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FLIGHT DIRECTOR INFORMATION AND PILOT PERFORMANCE IN INSTRUMENT APPROACHES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*
This report documents the results of a research effort conducted to identify problem areas encountered during instrument approaches and landings in an F-16A through adverse meteorological conditions. Phase I consisted of identification and simulation of visual conditions likely to produce the conflict/misorientation experienced under "real-world" conditions; and development of performance measurement standards for F-16A instrument landing system (ILS) training. During Phase II, an experiment was conducted using the F-16A flight simulator at the Aircrew Training Research Division of the Armstrong Laboratory (AL/HRA) to evaluate F-16A pilot performance with five different ILS instrument configurations: (1) Head-up display (HUD) with flight director, (2) HUD without flight director, (3) Panel instruments only, (4) Panel instruments and head-down flight director, (5) HUD with flight director, head-down flight director, and panel instruments. Normal aircraft configuration includes an ILS HUD display with flight director and cockpit panel instruments with raw ILS information. The head-down display, not found on the F-16A aircraft, was developed solely for the research. The display consisted of a head-down flight director that displayed computed steering commands from the HUD on the radar electro-optical display (REO). Twenty F-16A pilots with diverse levels of experience participated in this effort. Each pilot received 5 min of free flight and three practice approaches under benign visual flight rules (VFR) weather conditions. The pilot then flew 15 approaches (three under each condition, counterbalanced) under more difficult visual weather conditions which included scattered clouds, 1 1/2 mile-visibility, a 6,000-ft ceiling, and a 15-knot crosswind. The findings indicate that the HUD with flight director configurations (Conditions 1 and 5) resulted in the highest scores per approach, the head-down flight director configuration (Condition 3) gave the next highest scores, with the panel instruments only (Condition 4), the lowest scores. Because the pilots did not receive any training with the head-down display prior to the experiment, the implication is that any flight director system may be helpful in reducing problems during ILS approaches.

14. SUBJECT TERMS
Approaches, Flight director, Flight simulation, Flight simulators, Head-up displays, HUDs, Instrument landing system, Instruments, Landings, Panel instruments, Pilot performance

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PREFACE

The present effort was conducted by Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA), at the direct request of the 162d Tactical Fighter Group, to identify instrumentation problems encountered while completing instrument landings in adverse meteorological conditions.

The research was conducted under in-house Work Unit 1123-32-03, Tactical Scene Content Requirements. Principal investigator was Dr Elizabeth L. Martin (AL/ HRAU). The work was supported by Work Unit 2743-25-17, Flying Training Research Support, Contract F33615-90-C-0005, with the University of Dayton Research Institute. Contract monitor was Ms Patricia A. Spears (AL/HRAP).

We wish to express our appreciation to Ms Mary Willers (LINK), Mr Tom Dickens (LINK), Mr Vincent DiTore (LINK), Ms Elzbieta Jackiewicz, University of Dayton Research Institute (UDRI), Mr Jeff Clark, General Electric Government Services, (GEGS), Steve Stephens, Armstrong Laboratory, Aircrew Training Research Division, (AL/HRAE), and Ms Nancy Martinez (AL/HRAD) for their assistance in this effort. The combined expertise of Ms Willers, Mr Dickens, and Mr DiTore proved invaluable in developing the software to run the experiment. Ms Jackiewicz's competence in data analysis and patience with numerous problems in the data made the analysis a reality. Mr Clark's and Mr Stephens' expertise with the simulator visual system and database development greatly expedited this effort. Ms Nancy Martinez provided invaluable assistance in preparing numerous drafts and the written materials preliminary to implementing this investigation.

We also wish to express appreciation to the pilots from the 162d Tactical Fighter Group, Tucson, AZ; the 302d Tactical Fighter Squadron, Luke AFB, AZ; and the 58th Tactical Training Wing, Luke AFB, AZ. These pilots volunteered to participate in this research effort which was over and above their regular duties.

A special word of thanks is extended to Mr Dave Mumma (UDRI) for his valuable inputs from a subject matter expert's perspective.

FLIGHT DIRECTOR INFORMATION AND PILOT PERFORMANCE IN INSTRUMENT APPROACHES

SUMMARY

At the request of the 162d Tactical Fighter Group (TFG), this research was conducted to identify instrumentation problems encountered while completing instrument approaches and landings in adverse meteorological conditions. Many F-16A pilots hold a basic opinion that the current F-16A head-up display (HUD) make flying an instrument landing system (ILS) approach both easier and better. In this study, twenty F-16A pilots flew five ILS approaches, in various simulated weather conditions, with five different instrument configurations. These conditions included: (1) HUD with flight director, (2) HUD without flight director, (3) Panel instruments and head-down flight director, (4) Panel instruments only, and (5) HUD with flight director, head-down flight director, and panel instruments. The head-down display (HDD), not found on the F-16A fighter aircraft, was constructed solely for this research.

The findings indicate that the HUD with flight director configuration resulted in higher precision scores per approach. Even without prior training in the system, the head-down flight director configuration resulted in higher precision scores for each variable than with panel instruments only. However, the pilots did not like the HDD as it was configured. The implication is that any flight director display may be helpful in reducing problems during ILS approaches.

INTRODUCTION

The advent of HUDs has brought into question the appropriate use of HUDs for instrument flight, particularly as primary flight reference for instrument approaches. The most effective use of the HUD during instrument flight, for those aircraft with HUDs not certified as single source primary flight reference, has not been determined. The present study was undertaken at the request of the 162d Tactical Fighter Group (TFG) to identify performance problems associated with the use of the HUD and the various alternative instrument configurations in the F-16A while completing instrument approaches and landings in adverse meteorological conditions.

Some researchers have contended that HUDs cause operational problems (e.g., Roscoe, 1987). We believe these problems arise from perceptual distortions resulting from misaccommodation and convergence of the eyes to the HUD symbology. Others have argued that these claims are exaggerated (e.g., Newman, 1987), and that given proper training and instrument cross-check, any perceptual distortion can be compensated for.

Head-up displays provide the pilot with flight information presented in symbolic form on a combining glass within the pilot's forward field of view. The symbology is aligned with the aircraft flight path and is optically focused at infinity. Although HUD systems are optimized for weapons delivery, most displays are capable of providing some references for instrument flight. Air Force Manual (AFM) 51-37, Instrument Flying, states that existing HUDs are neither designed to replace head-down instrumentation nor are they intended to be used as a sole source reference for instrument flight. For the purpose of instrument flight, current HUDs provide performance information and can be included in the basic instrument cross-check after ensuring the HUD is functioning properly. This manual further states that there is not enough information displayed on the HUD to safely fly without reference to some head-down instruments. The HUD lacks tactical air navigation (TACAN) bearing, distance measuring equipment (DME), bank angle, and ILS raw data.

The flight director, as referenced in this study, does not refer to the Flight Director Systems referenced in AFM 51-37. ILS information in the F-16 is presented on the attitude direction indicator (ADI), horizontal situation indicator (HSI), and HUD when the Instrument Landing System/Navigation (ILS/NAV) mode is selected. In the F-16, the steering bars in the ADI and HUD always present raw ILS data. The only flight director steering available in the F-16 is located in the HUD, and consists of the Flight Director Steering Symbol, a small circle with a short vertical line, or "tail," which represents where the flight path marker should be placed. It is imperative that pilots coming from aircraft with an AFM 51-37 Flight Director System recognize the differences in the F-16 ILS presentations. In this report, the flight director steering symbol, in the HUD and in the special head-down radar electro-optical (REO) display, will both be referred to as flight directors.

The F-16A is not equipped with a flight director system in the head-down cockpit instrument ensemble, although this information is available in the HUD. While not absolutely essential for performing an ILS approach, flight director information makes the task substantially easier and safer. Air Force pilots have been trained since Undergraduate Pilot Training to perform ILS approaches using a flight director, thus establishing a well practiced habit. Since the ILS mode on the F-16A HUD provides flight director information, many F-16A pilots reportedly use the ILS HUD mode to accomplish instrument approaches.

Air Force policy on the use of the HUD is contained in AFM 51-37 and states that existing HUDs are not designed to replace head-down instrumentation nor are they intended to be used as a sole source reference for instrument flight. The manual also states that current HUDs provide performance information for instrument flight and can be included in the basic cross-check after ensuring the HUD is functioning properly. This manual further states that there is insufficient information on the HUD to safely fly without reference to some head-down instruments. The HUD lacks TACAN bearing, DME, bank angle, or ILS raw data. The HUD also lacks failure warning/ indication information.

The Air National Guard's (ANG) F-16A Conversion Phase Manual states that the primary purpose of the HUD during instrument flying is to make it easier to transition from instrument to visual conditions. The manual also indicates that the HUD aids visual lookout, reduces the necessity for inside-the-cockpit scanning, makes basic aircraft control easy, and eases transition to visual references during landing approaches in poor weather. The Phase Manual also points out that although the HUD is a great asset in instrument flying, it must be continually cross-checked with the primary flight instruments on the instrument panel. Because the HUD provides only a small view of a much bigger world and is harder to interpret than conventional cockpit instruments when situational awareness is lost, the ANG does not allow the HUD to be used for recovery from spatial disorientation, unusual attitude recoveries, lost wingman, and large performance transients unless no other attitude instruments are available. (Additional information on HUD advantages and limitations may be found in Appendix A.)

Thus, the instrumentation available in the aircraft, the typical pilot's habit patterns, and official doctrine regarding the use of the HUD for ILS approaches are placed in conflict. Many pilots report "off the record" that they do use the HUD as the primary flight instrument during ILS approaches. Since the pilots are not formally trained to do this, idiosyncratic techniques have been informally developed and passed on among the F-16A pilot community. From a training system design standpoint, this is not a desirable situation and may result in unsafe flying techniques.

Although issues relating to the proper use of the HUD for ILS approaches in the F-16A were the immediate impetus for the current study, other training issues relating to weather simulation and pilot debriefing capability were also of interest. Since their inception, simulators have been used to support instrument flight training. Because instrument flying has traditionally been a head-down activity, relatively little attention has been paid to simulating the out-of-the-cockpit visual scene. Many instrument trainers do not have a visual system. Most multi-purpose modern simulators with visual systems can simulate cloud ceilings and restricted visibility. However, there are many real-world weather conditions that can lead to confusion, misorientation, and disorientation that typically are not simulated. If modern computer-generated visual systems could create convincing representations of confusing or misorienting weather conditions, the realm of ground-based instrument flight training could be significantly extended. For the purpose of evaluating the use of the HUD for instrument approaches, it would be desirable to include the use of these types of visual conditions. Thus, a secondary objective of the present study was to create and evaluate certain simulated weather conditions that could induce some confusion, specifically, scud, tilted cloud banks, and ground fog. A configuration of ground lights that were at oblique angles to the ground were also included. Such lights are sometimes found along roads that climb hills surrounding an aircraft facility and may be momentarily perceived as level and parallel to the horizon.

Another issue of some operational interest was scoring a pilot's performance for the purposes of debriefing. Traditional laboratory type measures of performance are not well received by the pilot community. The pilots prefer measures that are interpretable in the terms used in a routine training environment. Therefore, an attempt was made to develop a scoring procedure which was acceptable to the pilots while retaining sensitivity to traditional measures.

METHODOLOGY

Design

The dependent variable was flying performance of the pilot under each of five experimental conditions. To control for order effects, an orthogonal set of four Latin Squares was used (Peterson, 1985, Chap 12). Each subject was assigned a specific order as defined by the design. Five experimental conditions were investigated. The conditions were defined by the ILS instrument conditions as shown in Table 1.

TABLE 1. ILS EXPERIMENT CONDITIONS

<u>Condition 1: Head-up Display with Flight Director</u>

No Head-Down Instrumentation

<u>Condition 2: Head-Up Display without Flight Director</u>

HUD with Glideslope (GLS) and Localizer Deviation Bars
No HUD Flight Director
No Head-Down Instrumentation

<u>Condition 3: Head-Down Instruments without Flight Director</u>

Altimeter (ALTM), Airspeed Indicator (AI), Vertical Velocity Indicator (VVI), Angle-of-attack (AOA) Indicator
ADI, HSI
No HUD
No Head-Down Flight Director

<u>Condition 4: Head-Down Instruments with Flight Director</u>

ALTM, AI, VVI, AOA Indicator,
ADI, HSI
Head-Down Flight Director
No HUD

<u>Condition 5: Combined Head-Up Display with Flight Director and Head-Down Instruments with Flight Director</u>

HUD with Flight Director
Head-Down Flight Director
ALTM, AI, VVI, AOA Indicator, ADI, HSI

Condition 1: Head-Up Display with Flight Director

The HUD provided all primary control and performance information except for engine information. The flight director mode could be selected and computed steering commands could be received. An explanation of the use of the HUD symbology with the flight director to perform the ILS task and a diagram of the HUD with/without the flight director may be found in Appendix B. A diagram of the HUD with flight director may be found in Figure 1.

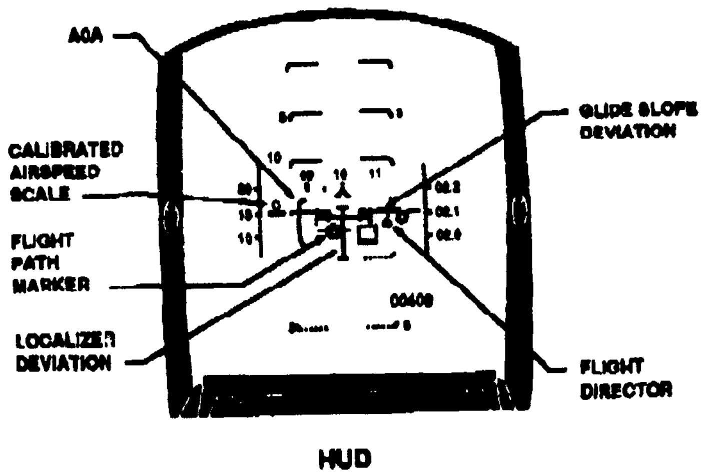

Figure 1. Head-up Display (HUD) with Flight Director

In this condition, the following head-down/cockpit flight instruments were inoperative: ALTM, AOA, VVI, AI, ADI, HSI, GLS indicator, and localizer.

Condition 2: Head-Up Display without Flight Director

This condition was the same as Condition 1, except there was no flight director and no computed steering command displays. This condition was a manual ILS using the HUD. A diagram of the HUD without the flight director may be found in Figure 2.

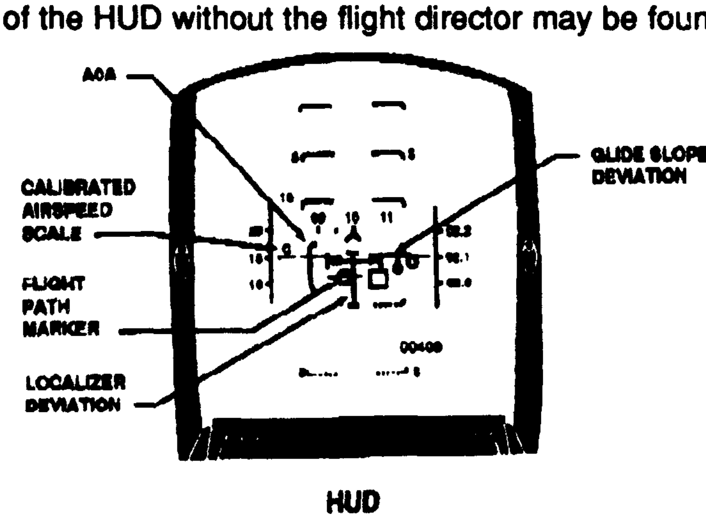

Figure 2. Head-up Display (HUD) without Flight Director

Condition 3: Head-Down Instruments without Flight Director

In this condition, the pilot performed a manual ILS using the head-down ALTM, AI, VVI, AOA indicator, HSI, and ADI. There were no computed steering commands. The HUD was turned off during this condition.

Condition 4: Head-Down Instruments with Flight Director

The REO display was modified to display head-down instruments with flight director information. This display was done solely for the purposes of this test and is not available in the F-16 aircraft. Appendix C contains more specifications on the head-down instruments with flight director, with diagrams of the ILS task using the head-down instruments with flight director. In addition, the head-down instruments without flight director method of performing the ILS task (the primary Air Force method) is also included in Appendix C.

Condition 5: Combined Head-Up Display with Flight Director and Head-Down Instruments with Flight Director

This condition was a combination of Conditions 1 and 4. All instrumentation was available. The pilot was free to use any or all of the instruments, including the HUD, to fly the ILS. This mode is not available in the F-16 aircraft because it does not have a head-down flight director.

Subjects

Twenty F-16 pilots with various experience levels (ranging from 260 to 7,500 flying hours and 15 to 1,600 F-16 hours) from ANG, Air Force Reserve (AFR), and active duty Air Force (AF) locations (see Table 2) served as subjects. Five pilots were instructor pilots; five were operational pilots; five were C/TX-Course students; and five were B-Course students.

TABLE 2. SUBJECT BACKGROUND

Five subjects were in each of the following categories

		Instructor Pilots	Operational Pilots	C-TX-Course Students	B-Course Students
Age	Mean	37.8	36.2	34.8	27.0
	S.D.	8.6	5.4	2.9	1.9
F-16 Hours	Mean	846.0	630.0	26.0	47.0
	S.D.	438.8	369.7	5.5	19.9
Flying Hours	Mean	3545.0	2818.2	2181.4	970.0
	S.D.	2402.6	1282.4	374.3	1155.7

Apparatus

The AL/HRA's F-16A Limited Field-of-View Dome simulator, equipped with fully operational flight controls cockpit instrumentation, and HUD was used in the study. The in-cockpit radar display was modified to provide head-down flight director information. This simulator does not have a motion system.

The Advanced Visual Technology System (AVTS) provided the visual display for the simulator. AVTS is a 10-channel Computer Image Generator (CIG), capable of generating 8,000 edges, 4,000 point features, 1,000 circular features, and 7 moving models every 16.6 ms. All 10 channels support texturing, a feature which provides velocity and surface orientation cues considered essential for low-level flight and other air-to-surface missions. Ferguson, Cody, and Petrie (1986) have documented system specifications for the AVTS. The AVTS full-color visual imagery was displayed in the 24 ft limited field-of-view dome.

The fixed, high resolution area of interest in this simulator is 40 degrees horizontal and 30 degrees vertical, while the elliptical background field of view is 140 degrees horizontal and 60 degrees vertical. A 5-degree optically blended transition area exists between the low resolution background and high resolution area of interest (AOI). The center of the AOI was boresighted with the nose of the aircraft. While the gear was down, the center of the AOI was slewed to the velocity vector, which rotated the visual display down as a function of approach speed.

Based on Defense Mapping Agency (DMA) digital terrain and feature data, the Tucson International Airport, the Goldwater Gunnery Range Complex, and Libby Army Airfield were modeled. The visual system simulates both day and night scenes. At night, the runway environment includes strobe lights, visual approach slope indicator (VASI) lights, and runway centerline and side lights.

For the Libby Army Airfield database a ceiling was created at 6,000 ft mean sea level (MSL) and scattered cumulus clouds were developed from 500 to 1,500 ft above ground level (AGL), while the ground elevation was 4,633 ft MSL. An attempt was made to create a visual illusion by including a string of "illusion lights" on the runway going up at a 45-degree angle to the right. The idea was to create a distraction to the pilot as both the runway lights and the "illusion lights" flashed in and out through the simulated cumulus clouds.

The basic element in the performance measurement system was a Gould 32/9780 system for initial capture, storage, retrieval and formatting of the behavioral data. Software needed for acquisition of the data recorded on the Gould computers was developed by AL/HRA contractor personnel. The data were then transferred to a DEC VAX 6310 for analysis using release 5.18 of the Statistical Analysis System (SAS) program.

Tasks

Each pilot was tested in the simulator three times in the same day for 1 h to 1 1/2 h each time. The specific events in each of the three simulator sessions were as follows:

Session 1:	5 min of free flight
	3 practice ILS approaches
	5 test ILS approaches
Session 2:	5 test ILS approaches
Session 3:	5 test ILS approaches

Free-Flight and Practice Trials

The 5-min free flight and the three practice ILS approaches were conducted in the Tucson area of the database. The free-flight time was used by the pilot to become familiar with the simulation. At the beginning of the practice trials, the pilot was initialized on a 21 nautical mile (nmi) dogleg for ILS runway 11L at Tucson. The pilot either performed a full-stop landing or executed a missed approach, at which time he was reinitialized on the dogleg for the next approach. During the practice trials, the HUD with the flight director, the head-down flight director, and the panel instruments were available. A researcher at the Instructor Operator Station (IOS) controlled the weather conditions and cleared the pilot for approach prior to each practice trial. The weather conditions in the familiarization period and practice trials were as follows:

Practice 1. Day, clear, unlimited visibility, calm winds.

Practice 2. Night, Visual Flight Rules (VFR), 10-knot winds at 146 degrees.

Practice 3. Night, cloud deck at 5,000 ft MSL, 3-mile visibility, calm winds.

Test Trials

The task for the test trials was to perform an ILS approach and either a full-stop landing or a missed approach. For these tests, Libby Airfield was used. The simulator was initialized on a 17.5 nmi dogleg for Libby ILS runway 26 prior to each trial.

In each of the three test sessions the pilot flew five approaches, one under each of the five conditions described in Table 1 (HUD with Flight Director, HUD without Flight Director, Head-Down Instruments without Flight Director, Head-Down Instruments with Flight Director, and Combined HUD with Flight Director and Head-Down Instruments with Flight Director).

Subjects were randomly assigned to a specific treatment order, as determined by the design. This same order was used in each session. Prior to each test trial, a researcher at the IOS relayed the weather and cleared the pilot for the approach. The weather on all test trials was as follows:

Night
Ceiling: 6,000 ft MSL
Scattered clouds 500-1,500 ft AGL
Visibility: 1 1/2 miles
Wind: Direct crosswinds at 166 degrees, 15 knots

A complete list of the weather conditions for both the warm-up and test sessions, which were provided to the pilot prior to each approach, may be found in Appendix D.

Performance Feedback

Feedback in the form of direction of GLS and localizer deviation was provided by a researcher at the IOS following each practice trial. Feedback was not provided for the test trails. Following the three test sessions, the pilot was given a summary printout of performance on the test trials.

Measurements

Performance Measures

Data were collected on the following parameters: altitude MSL, X axis (forward) velocity, Y axis (left - right) velocity, Z axis (up - down), heading, pitch, roll, latitude, longitude, indicated airspeed, AOA, weight on wheels, localizer deviation (left - right), glideslope deviation (up - down), left - right of touchdown point, horizontal distance to touchdown point, AGL altitude, line of sight distance to touchdown point, speed brake position, flight director azimuth (left - right), flight director elevation (up - down), flight path marker elevation (up - down), flight path marker azimuth (left - right), selected course (cosine), selected course (sine), % revolutions per minute (RPM), stick force pitch, stick force roll, and power level angle throttle position.

Scoring Algorithm

A scoring algorithm was created by subject matter experts based on these measures. This algorithm may be found in Appendix E along with a sample printout of an actual approach.

Procedure

Prebriefing

Each pilot viewed a 10-min videotaped prebriefing prior to the first simulator session. The pilot also studied a written handout which covered the basics of the research and contained information on the head-down flight director. This handout may be found in Appendix F.

Debriefing

Following completion of the third session, each pilot received a debriefing which included a summary printout of his performance on the test trials. At this time the pilot also completed a questionnaire about the simulation and research. The first seven items consisted of a five-point scale with the following verbal anchors:

1 = Strongly Disagree

2 = Somewhat Disagree

3 = Undecided

4 = Somewhat Agree

5 = Strongly Agree

Table 3 contains the results of the debriefing questionnaire. This questionnaire may be found in Appendix G.

Schedule

All three test sessions, ranging from 1 h to 1 1/2 h in length were flown in the same day. The pilots received at least a 10-min break between sessions.

TABLE 3. RESULTS OF DEBRIEFING QUESTIONNAIRE

Topic	Overall	Instructor Pilots	Operational Pilots	C/TX-Crs Studs	B-Crs Studs
Like the way the simulator flies	x=3.8 SD=0.9	x=3.4 SD=0.9	x=4.2 SD=0.4	x=4.0 SD=0.4	x=3.6 SD=0.9
Sim flies like the aircraft	x=3.5 SD=0.8	x=3.0 SD=1.0	x=3.4 SD=0.9	x=3.8 SD=0.4	x=3.6 SD=0.9
Sim visual caused disorientation	x=2.7 SD=1.2	x=3.2 SD=1.1	x=2.8 SD=1.3	x=2.2 SD=1.1	x=2.4 SD=1.5
Disorientation during head-up phase	x=3.0 SD=1.3	x=3.6 SD=0.9	x=3.0 SD=1.6	x=3.0 SD=1.4	x=2.4 SD=1.3
Disorientation during head-down phase	x=2.1 SD=1.1	x=1.8 SD=0.8	x=2.0 SD=1.4	x=1.8 SD=0.4	x=2.6 SD=1.7
Changed my ILS technique	x=2.6 SD=1.3	x=2.2 SD=1.6	x=2.4 SD=1.5	x=3.0 SD=1.2	x=2.8 SD=1.1
I fly better approaches as a result of this study	x=3.5 SD=0.8	x=3.4 SD=0.9	x=3.8 SD=0.4	x=3.2 SD=0.8	x=3.6 SD=0.9
Like head-down flt. dir.	x=2.2 SD=1.3	x=1.8 SD=0.8	x=2.4 SD=0.4	x=1.2 SD=0.4	x=3.2 SD=1.3
Like to see head-down flt. dir. in the aircraft	x=3.9 SD=1.4	x=3.0 SD=1.9	x=3.4 SD=1.5	x=4.4 SD=0.9	x=4.8 SD=0.4

SD = standard deviation

RESULTS

Two basic types of measures were employed in this study; the actual performance data as collected from the flight simulator, and the scores derived from the scoring algorithm (Appendix E). These measurements were collected in three segments of the ILS course. The segments were defined as follows: Fly the Approach was defined as the segment from GLS intercept to the middle marker (1.0 nmi DME). Within the Fly the Approach segment, the performance data were summarized by computing a mean and a standard deviation for each of the performance variables (10 Hz sampling rate). Decision Height was defined as the first computer frame ("snapshot") when the aircraft reached decision height (200 ft AGL). Touchdown was defined as the first computer frame ("snapshot") when initial weight on wheels occurred.

The subjects flew for three sessions. During each session, each subject flew each of the five ILS instrument conditions according to a predetermined order. The responses for each of the three segments were averaged (means calculated) across the three trials for each subject condition combination. These mean scores were then analyzed using an analysis of variance (ANOVA) for a Latin Square changeover design (Peterson, 1985, chap. 12). This design provides for various analyses of carry-over and blocking effects. The initial analysis indicated that no important carry-over or transfer effects were present indicating main effects were not confounded with treatment order. The data were then analyzed using a randomized block ANOVA with Landings and Subjects as blocking factors and ILS Conditions as the treatment effect. Since the only factor of interest was that due to ILS Conditions, it will be the only one reported.

Fly the Approach

Performance Data. The dependent variables analyzed in this segment were: Mean and Standard Deviation of Flight Path Angle, Mean and Standard Deviation of Localizer Deviation, and Mean and Standard Deviation of GLS Deviation. An initial multivariate analysis of variance (MANOVA) of the ILS conditions was significant (Wilks' lambda = .196, approximate $F(24, 235) = 5.836$, $p < .0001$). The results of the individual ANOVAs along with the means for the five ILS conditions may be found in Appendix H. Mean Flight Path Angle was not significant, but the Standard Deviation of Flight Path Angle was. The remaining dependent variables (Mean GLS Deviation, Standard Deviation of GLS Deviation, Mean Localizer Deviation, and Standard Deviation of Localizer Deviation) were all significant. Figure 3 presents the mean performance for each of the five conditions.

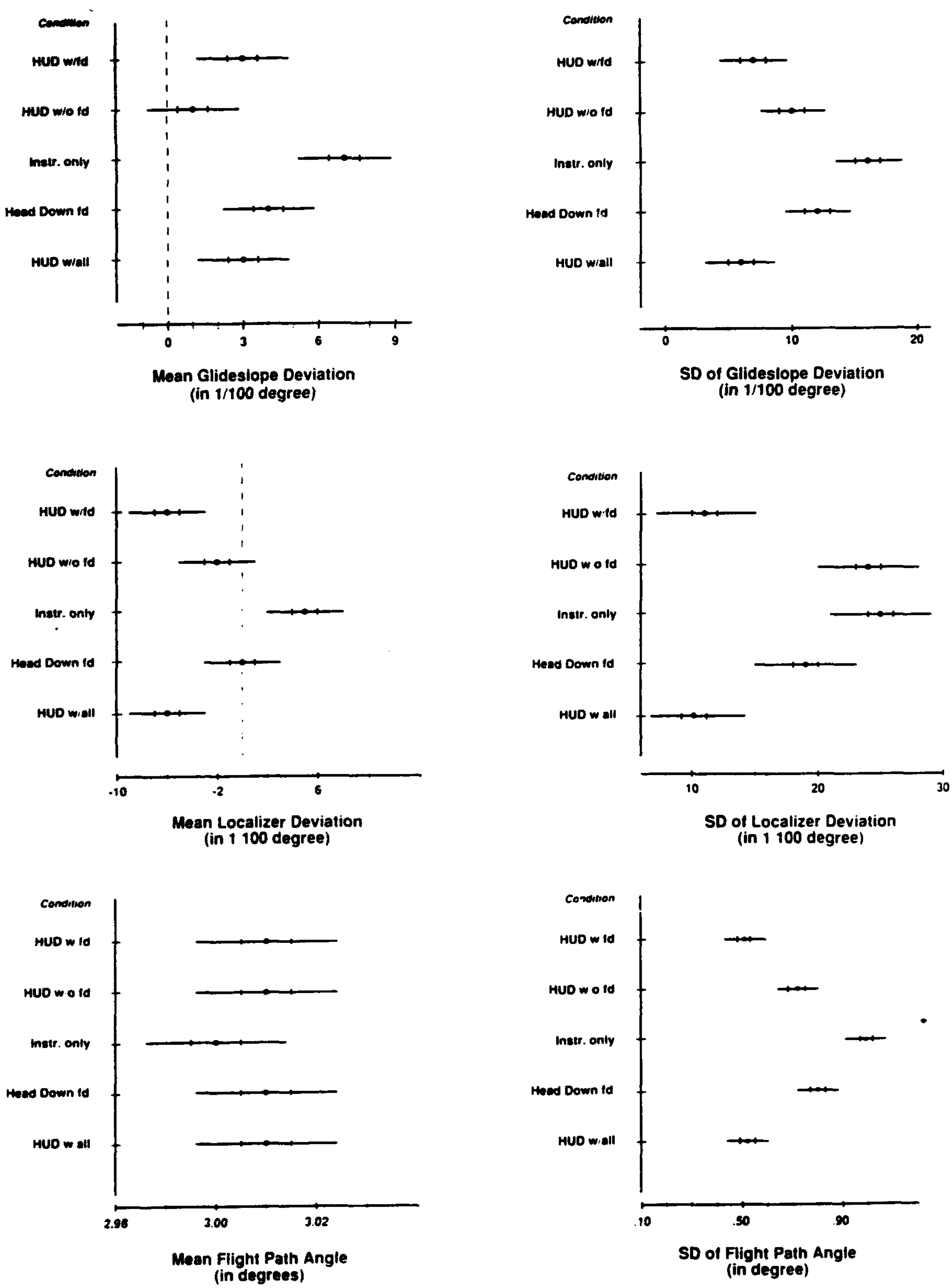

Figure 3. Performance measures for Fly the Approach. Mean performance rating for each of the five ILS conditions. Outer error bars represent a 95% confidence interval. Inner error bars represent a 50% confidence interval.

Scoring Algorithms. Using the scoring algorithms outlined in Appendix E, scores were derived for each subject within each condition. The scores were for GLS Deviation, Localizer Deviation, Flight Path Angle, and AOA. The initial MANOVA was significant (Wilks' lambda = .034, approximate $F(16, 221) = 26.715$, $p < .0001$). The results of the individual ANOVAs along with the means for each condition may be found in Appendix H. All of the tests were significant.

Decision Height

Performance Data. The dependent variables analyzed in this "snapshot" (one computer frame) were: Flight Path Angle, Localizer Deviation, and GLS Deviation. The MANOVA was significant (Wilks' lambda = .578, approximate $F(12, 185) = 3.562$, $p < .0001$). The ANOVA results along with the means may be found in Appendix H. All of the tests were significant. Figure 4 presents the mean performance for each of the five conditions.

Scoring Algorithms. The scores from the scoring algorithms were calculated for the following: Localizer Deviation, GLS Deviation, AOA, and Flight Path Angle. The MANOVA was significant (Wilks' lambda = .396, approximate $F(16, 221) = 4.685$, $p < .0001$). The univariate ANOVAs were all significant as can be seen in Appendix H.

Touchdown

Performance Data. The dependent variables analyzed for this final snapshot were: Vertical Velocity, Flight Path Deviation, Drift Rate, Localizer Deviation, and Distance from Touchdown Point. The initial MANOVA was not significant (Wilks' lambda = .747, approximate $F(20, 226) = 1.04$, $p = .4169$). None of the univariate ANOVAs for the touchdown, as shown in Appendix H were significant. Figure 5 presents the mean performance for each of the five conditions.

Scoring Algorithms. The derived scores from the scoring algorithms for touchdown were: Centerline Deviation, AOA, Distance from Touchdown, Flight Path Angle, and Drift. The MANOVA was not significant (Wilks' lambda = .676, approximate $F(20, 226) = 1.419$, $p = .1145$). None of the univariate ANOVAs were significant with the exception of Centerline Deviation ($F(4, 72) = 2.69$, $p = .0378$). This difference is not great and is not confirmed by the other dependent variables (performance data and scoring algorithms) for touchdown.

DISCUSSION

Many experienced F-16 pilots believe that current HUDs improve ILS performance. These pilots developed this opinion through their own operational experience outside of the formal training system. The results of this study tend to validate this opinion. Pilots did fly "better" ILS approaches when flight director information was available.

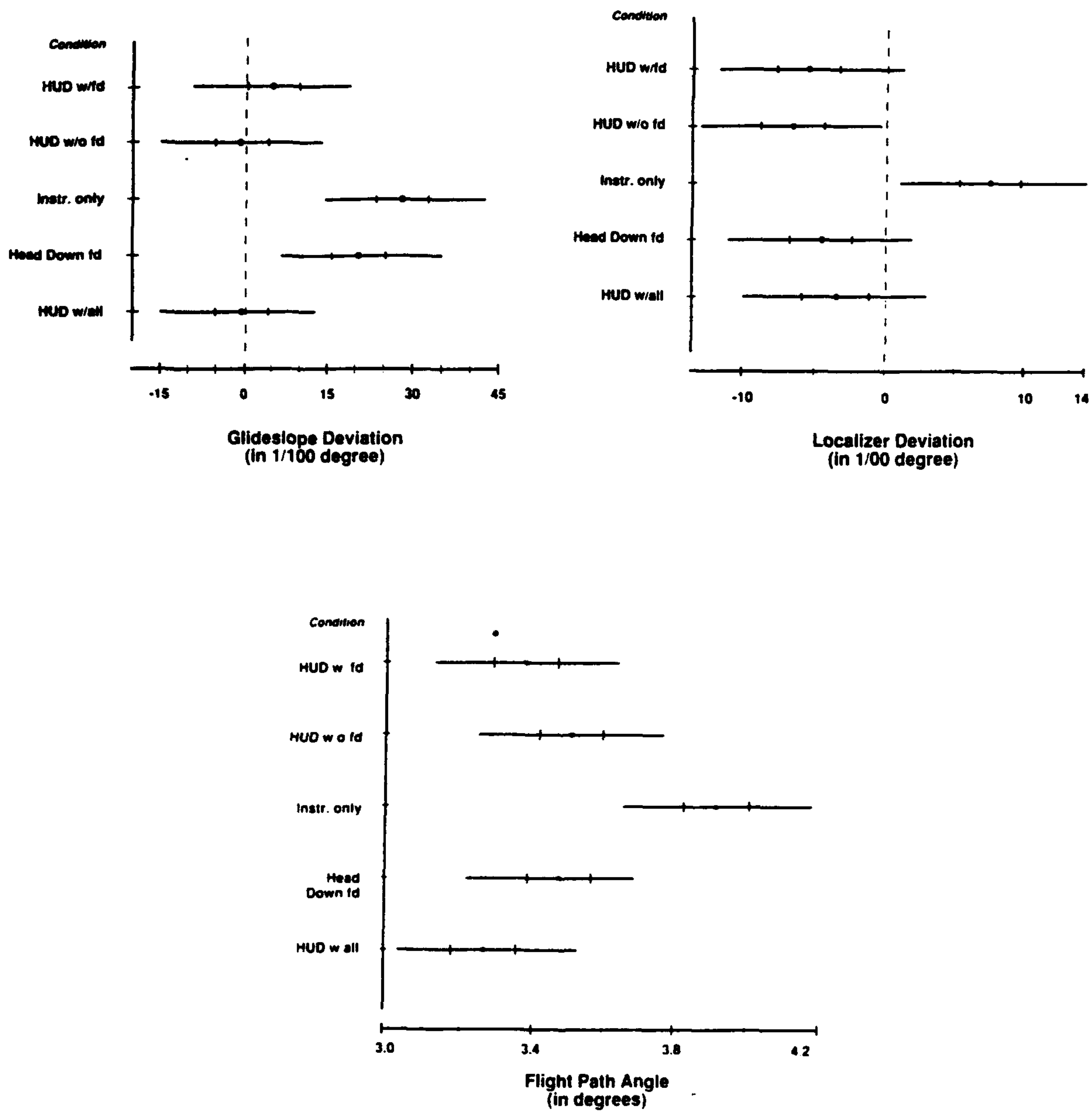

Figure 4. Performance measures for Decision Height. Mean performance rating for each of the five ILS conditions. Outer error bars represent a 95% confidence interval. Inner error bars represent a 50% confidence interval.

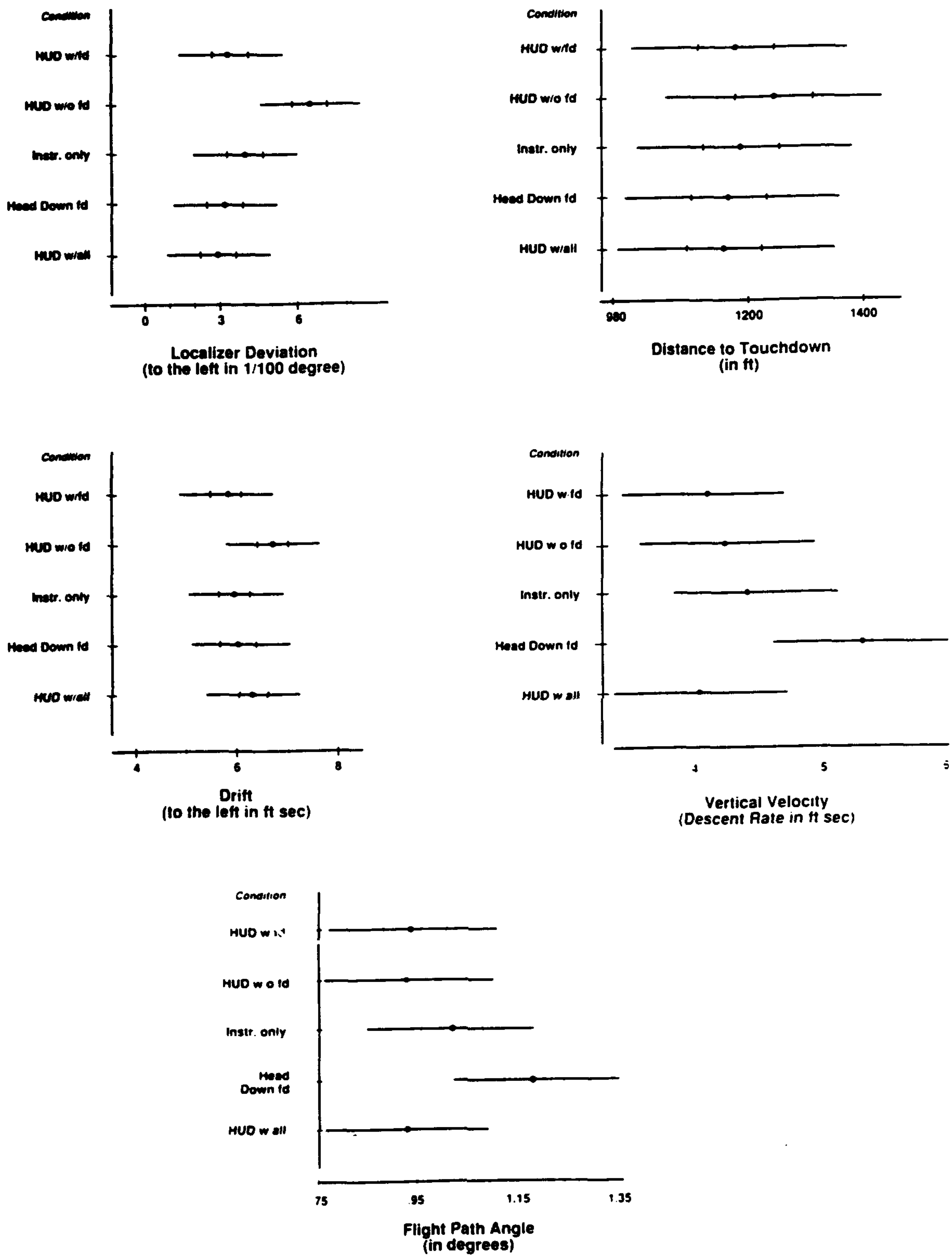

Figure 5. Performance measures for Touchdown. Mean performance rating for each of the five ILS conditions. Outer error bars represent a 95% confidence interval. Inner error bars represent a 50% confidence interval.

The similar pilot performance observed in Condition 1 (HUD with Flight Director) and Condition 5 (Combined HUD with Flight Director and Head-Down Instruments) implies that the current F-16A HUD configuration is an effective sole source reference for ILS approaches. One of the major advantages of the HUD appears to be when the Flight Director is used. This advantage can be seen in the difference in standard deviation of Localizer Deviation during the Fly the Approach segment between the two HUD conditions: HUD with Flight Director (Condition 1) and HUD without Flight Director (Condition 2). The SD is a measure of variability; large SDs indicate large variability in deviations from the localizer. These results indicate that the HUD with Flight Director provides the pilot with more consistent control in tracking the localizer.

The advantage of the Flight Director is not surprising, since all fighter pilots are initially trained in aircraft that have various configurations of a Flight Director. The transition to the F-16A places the pilot in a difficult situation; either he concentrates upon the flight director information available only on the HUD (disregarding the regulations), or he attempts to use both the HUD and panel instrumentation together.

The impact of specific training on the proper use of the HUD needs to be investigated. For example, are the differences in performance greater during more severe weather conditions? Under what, if any, conditions is HUD ILS performance degraded? Can this effect be overcome with proper training? The answers to these questions directly impact the operational safety of F-16 operations. The United States Air Force (USAF) has typically lost two F-16s per year over the last 6 years.

Research should concentrate on answering these questions and delivering specific findings and recommendations to those responsible for developing and delivering the formal instrument training to F-16A pilots. Assistance should be provided to develop a complete academic, simulator, and aircraft training syllabus to optimize the use of the HUD for instrument approaches. Apparently, pilots will use the HUD regardless of whether the skills are formally or self-taught. The goal should be to establish a validated training program and improve upon it over time.

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APPENDIX A

HUD ADVANTAGES AND LIMITATIONS

HUD Advantages

a. A flight path marker (FPM) displays the direction of the aircraft velocity vector.

b. The HUD allows more precision.

1. The HUD provides higher resolution heading information. The Horizon Situation Indicator can be read to +/- 1 degree to -2 degrees. The HUD can be read +/- 1/2 degree.

2. The HUD provides higher resolution of pitch indications. The Attitude Direction Indicator can be read +/- 1/2 degree -1 degree. The HUD can be read to +/- 1/4 degree. ILS command steering can be easily followed.

3. The HUD provides precise control of the velocity vector to +/- 1/4 degree in both azimuth and elevation.

HUD Design Limitations

a. The HUD is not equipped with caution or warning signals for failures; therefore, the HUD should always be cross-checked with the head-down instruments.

b. The FPM

1. Can be in error with excessively degraded inertial navigation system.

2. At high drift angles, an "X" appears on the FPM and will not correctly indicate the aircraft vector.

3. Precise bank angle readings (+/- 10 degrees) are more difficult with the HUD than with the ADI.

c. Revolutions per minute must be used for power control.

d. Head movement is required to see all of the HUD symbology.

HUD Operational Limitations

a. The FPM can cause confusion.

b. The HUD can be disorientating.

1. Looking through the HUD when going in and out of clouds can be disorienting.

2. The movement of symbology in the HUD in turbulence may produce vertigo.

3. Situational interpretation is different in the HUD.

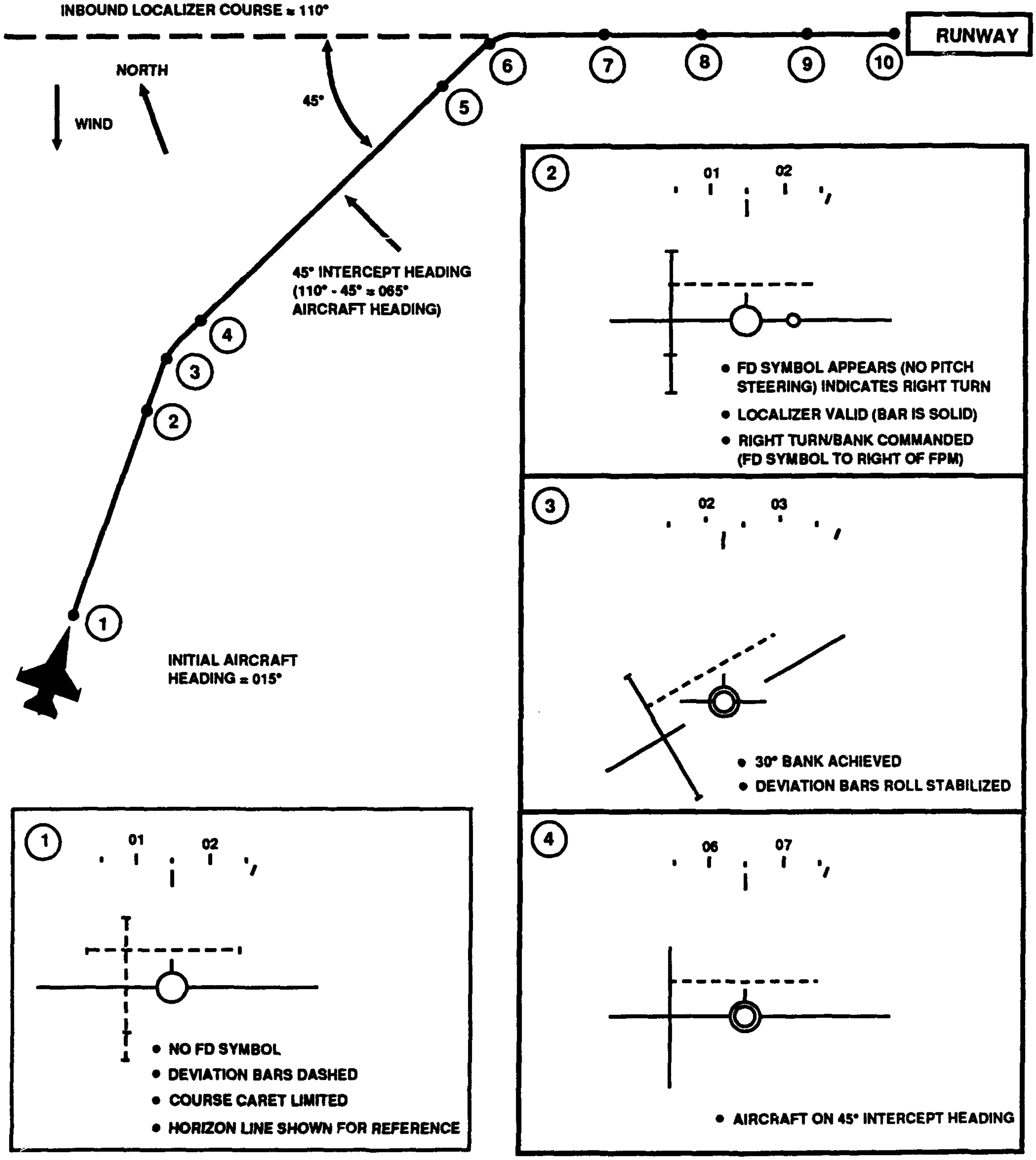
c. The HUD intensity brightness can be distracting.

d. Without proper training on the correct use of the HUD, channelized attention/fixation on HUD symbology can lead to lack of situation awareness and disorientation during critical phases of flight.

e. Without proper training, the HUD does not provide an easily interpreted picture of aircraft attitude during recovery from unusual attitude/lost wingman, when the pilot needs information rapidly. In addition, bank angle and pitch attitude can be easily misinterpreted.

APPENDIX B

HUD SYMBOLOGY (WITH FLIGHT DIRECTOR)



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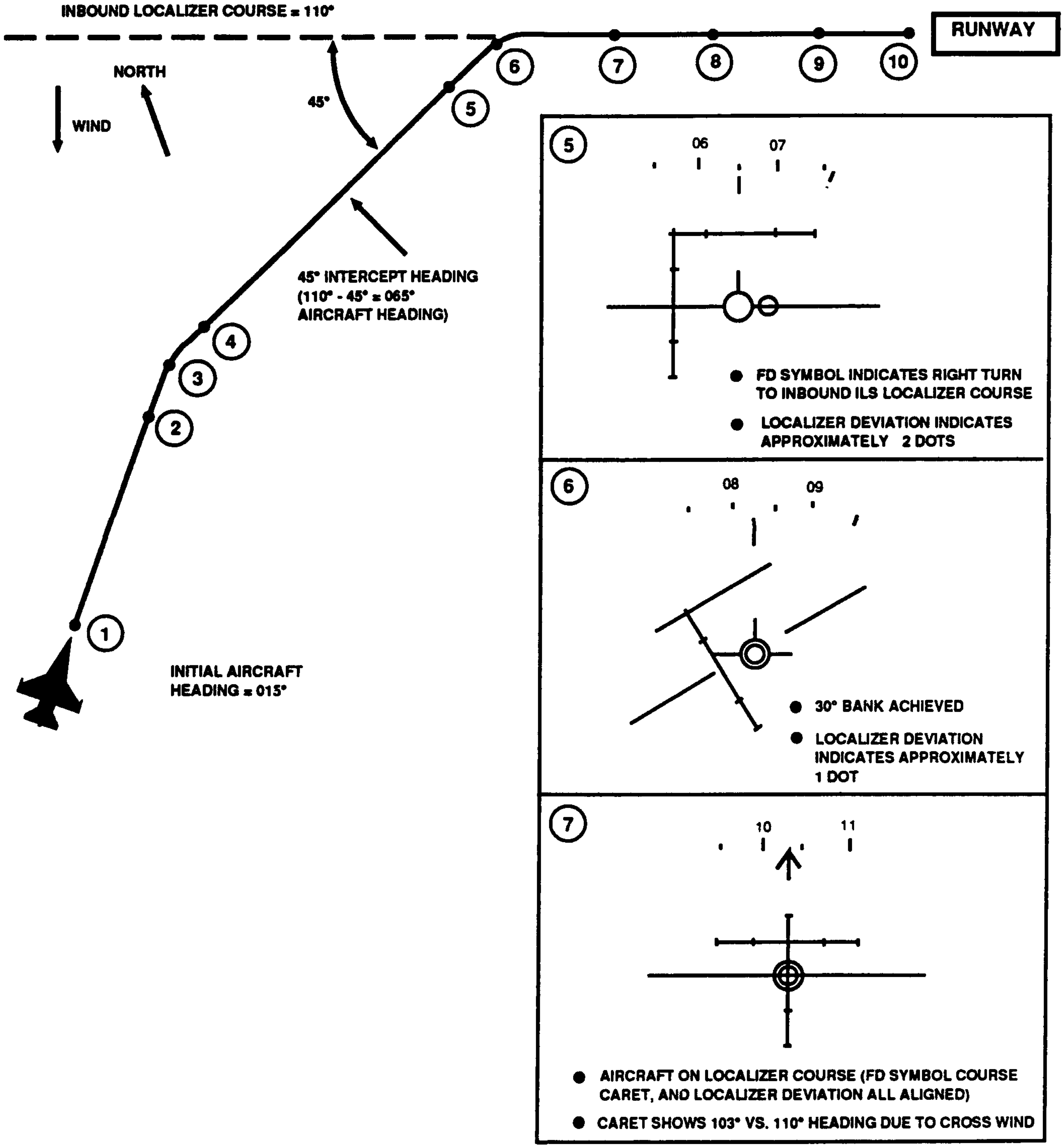
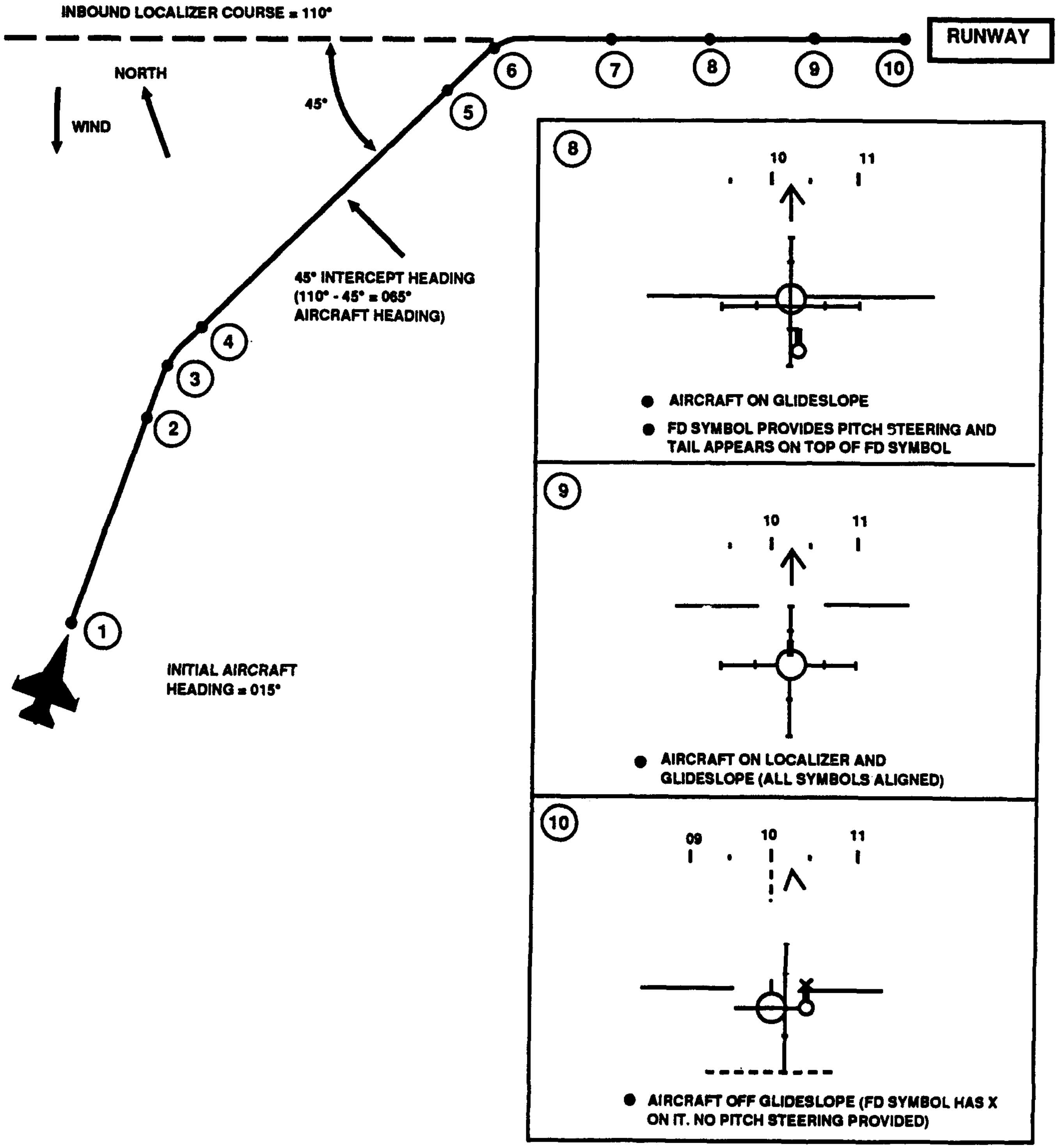
HUD SYMBOLOGY (WITH FLIGHT DIRECTOR)

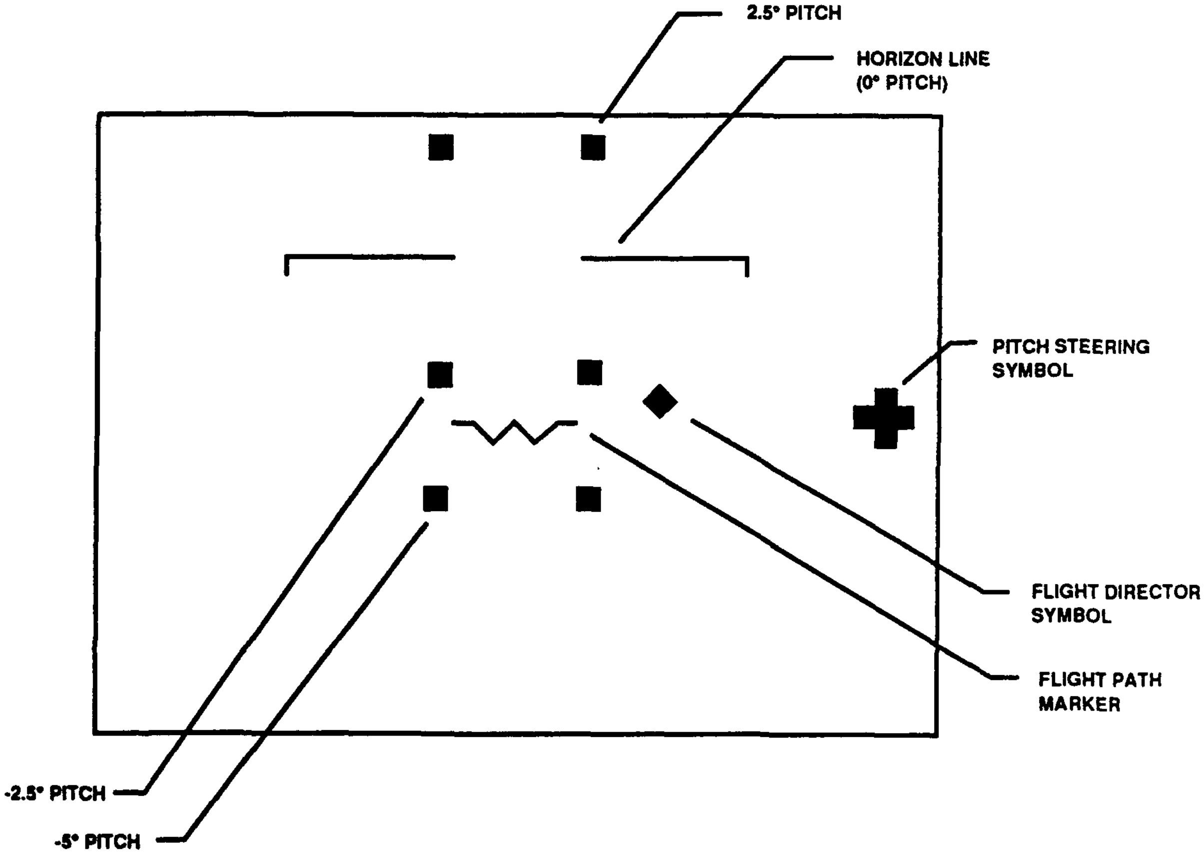


HUD SYMBOLOGY (WITH FLIGHT DIRECTOR)

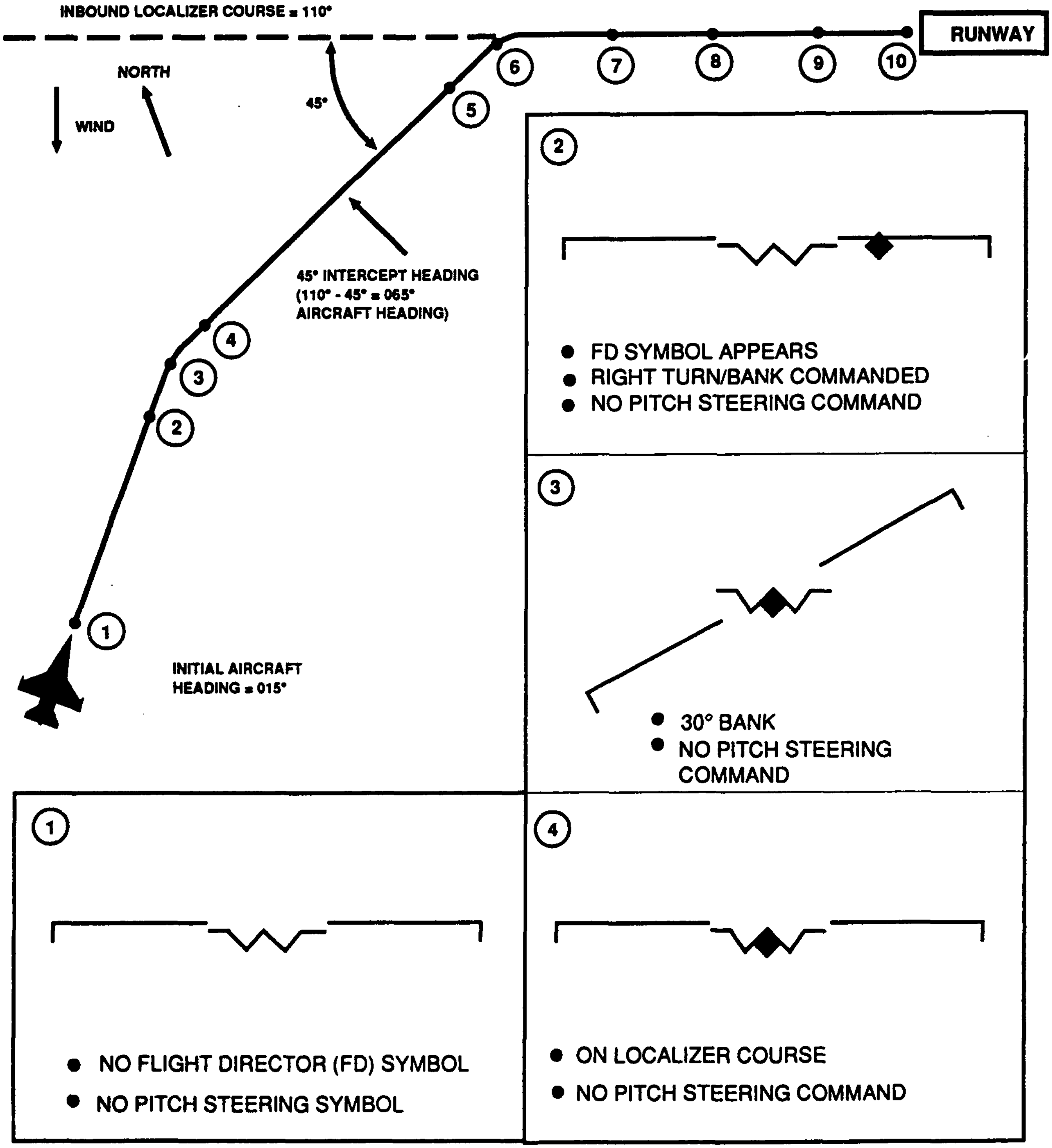


APPENDIX C

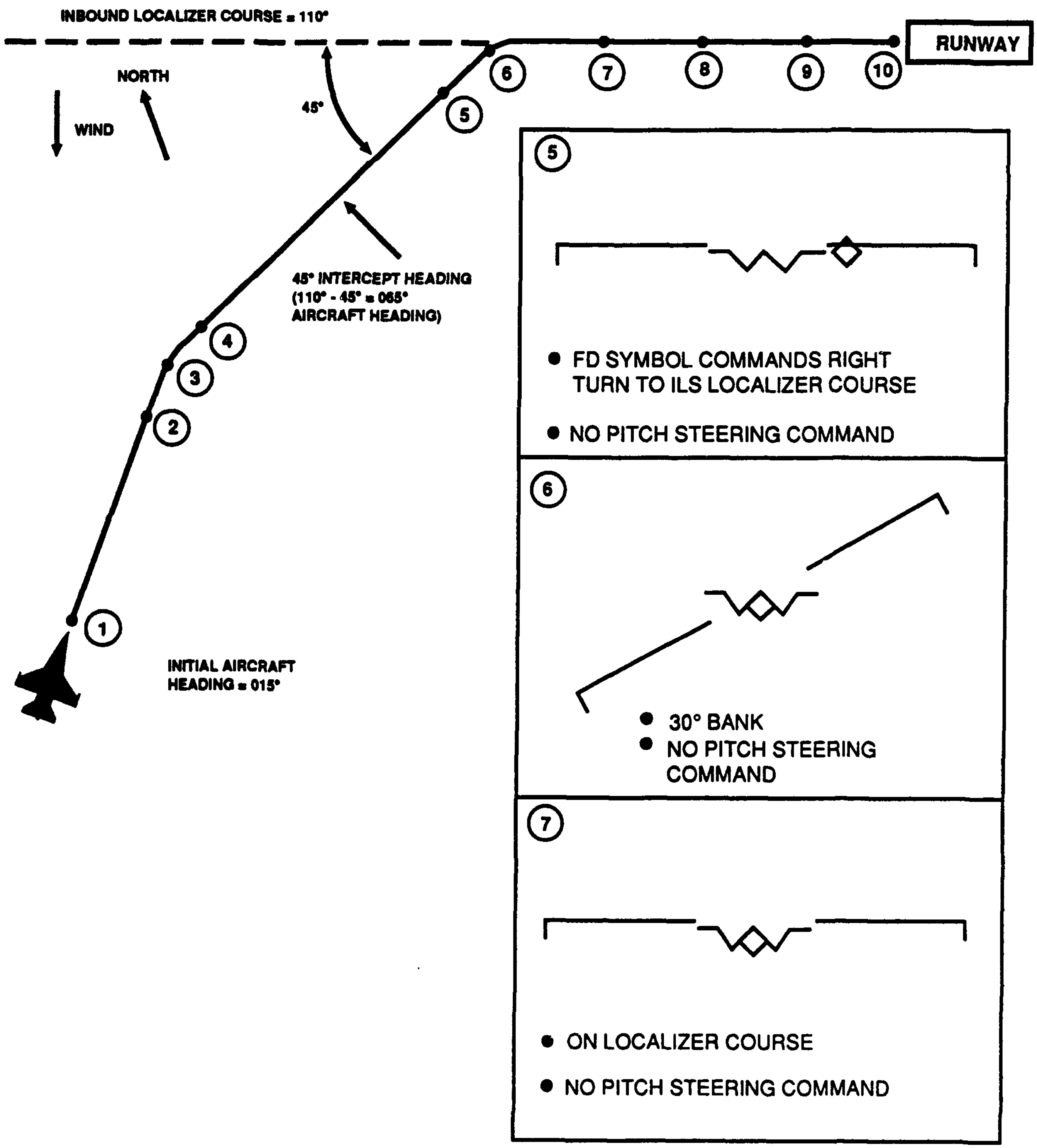
HEAD-DOWN FLIGHT DIRECTOR



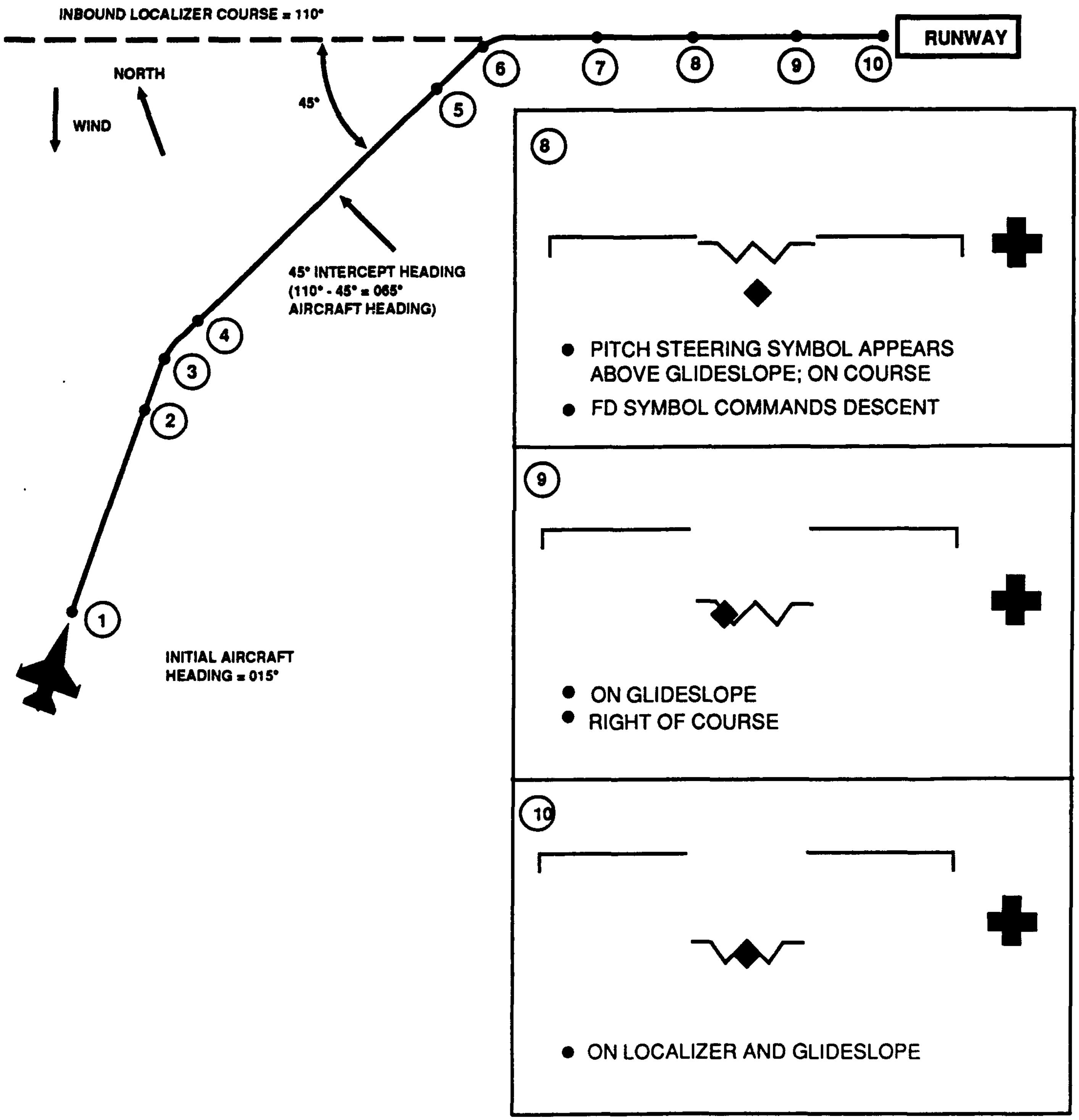
HEAD-DOWN FLIGHT DIRECTOR SYMBOLOGY



HEAD-DOWN FLIGHT DIRECTOR SYMBOLOGY

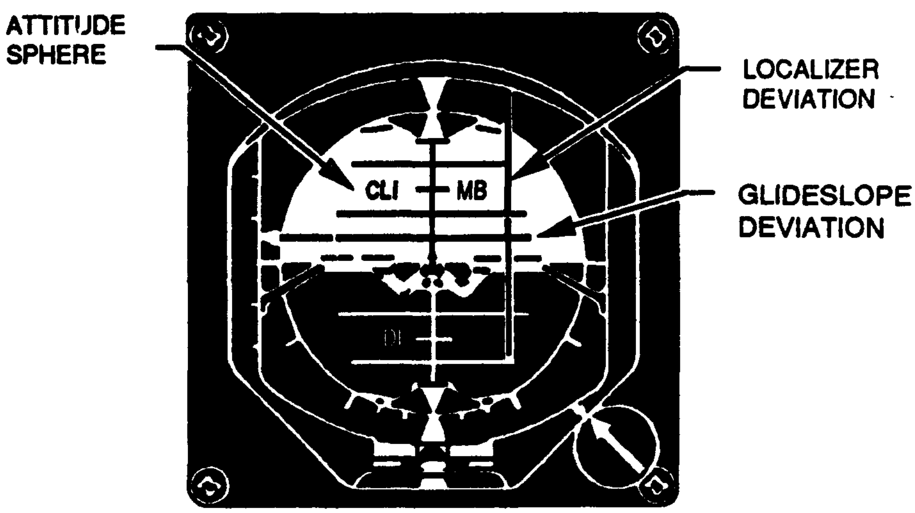


HEAD-DOWN FLIGHT DIRECTOR SYMBOLOGY



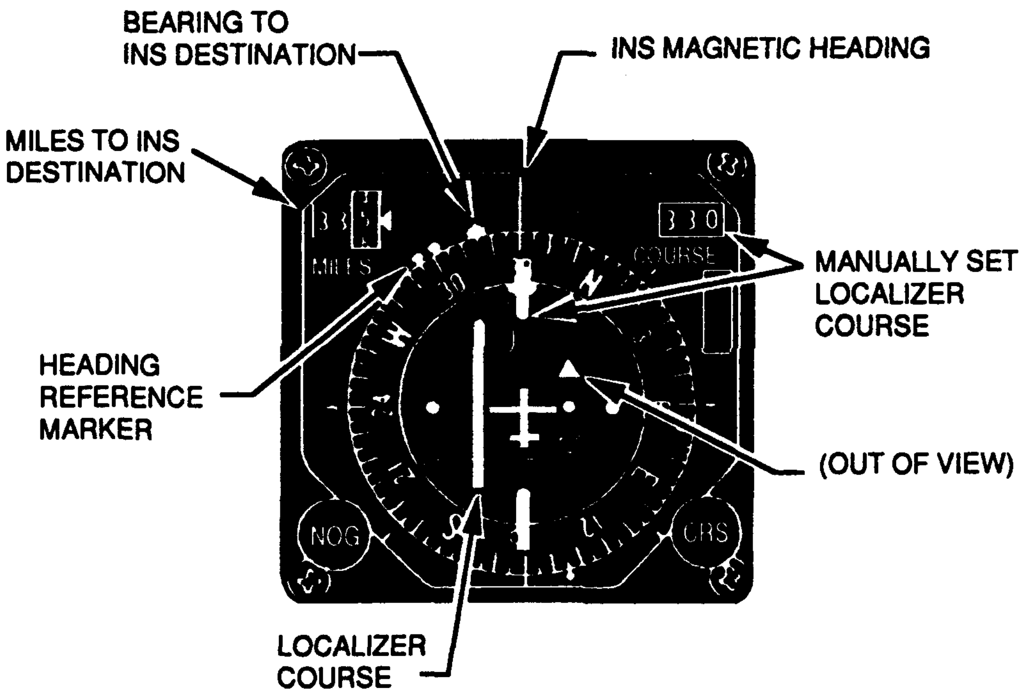
HEAD DOWN WITHOUT FLIGHT DIRECTOR
(PRIMARY AIR FORCE METHOD)

ATTITUDE DIRECTOR INDICATOR (ADI)



NOTE: Glideslope and localizer bars indicate deviation only, not steering.

HORIZONTAL SITUATION INDICATOR (HSI)



ALSO: ALTIMETER, AIRSPEED INDICATOR, VERTICAL VELOCITY INDICATOR, ANGLE OF ATTACK INDICATOR

APPENDIX D

WEATHER CONDITIONS/RADIO CALLS

PRACTICE 1

INSTRUMENTS:	All instruments: HUD with flight director, head-down flight director, panel instruments
WEATHER:	Day Clear Unlimited visibility Calm winds
POSITION:	21 nmi on a dogleg for ILS runway 11L at Tucson
ALTIMETER:	29.92
TURN:	To heading of 085^{o}
MAINTAIN:	085^{o} and 6,000' to intercept the localizer

Cleared for the approach

Call when ready

PRACTICE 2

INSTRUMENTS:	All instruments: HUD with flight director, head-down flight director, panel instruments
WEATHER:	Night VFR Winds are 146^{o} at 10 kts
POSITION:	21 nmi on a dogleg for ILS runway 11L at Tucson
ALTIMETER:	29.92
TURN:	To heading of 085^{o}
MAINTAIN:	085^{o} and 6,000' to intercept the localizer

Cleared for the approach

Call when ready

PRACTICE 3

INSTRUMENTS:	All instruments: HUD with flight director, head-down flight director, panel instruments
WEATHER:	Night Cloud deck at 5000' MSL 3-mile visibility Calm winds
POSITION:	21 nmi on a dogleg for ILS runway 11L at Tucson
ALTIMETER:	29.92
TURN:	To heading of 085°
MAINTAIN:	085° and 6,000' to intercept the localizer

Cleared for the approach

Call when ready

CONDITION 1

INSTRUMENTS:	(a) HUD with flight director (b) No head-down flight director (c) No panel instruments
WEATHER:	Night Ceiling at 6000' MSL Scattered clouds from 500 - 1,500 AGL 1 1/2-mile visibility Scud Cross wind from 166^{o} at 15 kts No ground fog
POSITION:	17.5 nmi on a dogleg for ILS runway 26 at Robby
ALTIMETER:	29.92
MAINTAIN:	218^{o} and 8,200' to intercept the localizer

Cleared for the approach

Call when ready

CONDITION 2

INSTRUMENTS:	(a) HUD without flight director (b) No head-down flight director (c) No panel instruments
WEATHER:	Night Ceiling at 6,000' MSL Scattered clouds from 500 - 1,500' AGL 1 1/2-mile visibility Scud Cross wind from 166° at 15 kts No ground fog
POSITION:	17.5 nmi on a dogleg for ILS runway 26 at Robby
ALTIMETER:	29.92
MAINTAIN:	218° and 8,200' to intercept the localizer

Cleared for the approach

Call when ready

CONDITION 3

INSTRUMENTS:	(a) Head-down flight director (b) Panel instruments (c) No HUD
WEATHER:	Night Ceiling at 6,000' MSL Scattered clouds from 500 - 1,500' AGL 1 1/2-mile visibility Scud Cross wind from 166^{o} at 15 kts No ground fog
POSITION:	17.5 nmi on a dogleg for ILS runway 26 at Robby
ALTIMETER:	29.92
MAINTAIN:	218^{o} and 8,200' to intercept the localizer

Cleared for the approach

Call when ready

CONDITION 4

INSTRUMENTS:	(a) Panel instruments (b) No HUD (c) No head-down flight director
WEATHER:	Night Ceiling at 6,000' MSL Scattered clouds from 500 - 1,500' AGL 1 1/2-mile visibility Scud Cross wind from 166^{o} at 15 kts No ground fog
POSITION:	17.5 nmi on a dogleg for ILS runway 26 at Robby
ALTIMETER:	29.92
MAINTAIN:	218^{o} and 8,200' to intercept the localizer

Cleared for the approach

Call when ready

CONDITION 5

INSTRUMENTS:	(a) HUD with flight director (b) Head-down flight director (c) Panel instruments
WEATHER:	Night Ceiling at 6,000' MSL Scattered clouds from 500 - 1,500 AGL 1 1/2-mile visibility Scud Cross wind from 166^{o} at 15 kts No ground fog
POSITION:	17.5 nmi on a dogleg for ILS runway 26 at Robby
ALTIMETER:	29.92
MAINTAIN:	218^{o} and 8,200' to intercept the localizer

Cleared for the approach

Call when ready

APPENDIX E

ILS EXPERIMENT SCORING ALGORITHM

I. <u>INTERCEPT LOCALIZER</u>:		85 POINTS
Scored immediately upon scenario start		
ILS/TACAN or ILS/NAV switch	5	
Localizer course set	5	
Heading held greater than 80% of time:		25 points
+/- 5 degrees	25	
+/- 10 degrees	10	
+/- 20 degrees	5	
else	0	
Altitude held between 8,000 and 9,000 ft MSL: Initial altitude of 8,200 ft MSL		15 points
100% of the time	15	
else	0	
Airspeed held greater than 80% of the time:		10 points
KAIS < 250 knots and AOA <= 11 degrees	10	
else	0	
Leadpoint turn held greater than 80% of the time: Scored from 3.5 degrees localizer deviation to 1/2 dot localizer deviation		25 points
+/- 3/4 degree	25	
+/- 1-1/2 degree	15	
else	0	

II. FLY LOCALIZER COURSE: 75 POINTS

Scored from 1/2 dot deviation to GLS intercept

Localizer held greater than 80% of the time: 25 points

+/- 1/2 dot	25	
+/- 1 dot	20	
+/- 1-1/2 dots	10	
else	0	

FPM on flight director over 80% of the time: 25 points
Azimuth only

+/- 1 degree	25	
+/- 2 degrees	10	
else	0	

Altitude held between Vector altitude (9,000')
and GLS intercept altitude (6,600'): 75 points

100% of the time	15	
80% of the time	10	
60% of the time	5	
else	0	

Airspeed held greater than 80% of the time: 10 points

KAIS < 250 knots and AOA <= 11 degrees	10	
else	0	

III. INTERCEPT GLIDESLOPE: 50 POINTS

Flight director activated nmi before outer marker: 25 points
Outer marker is at 5.0 nmi DME

Speed brakes out greater than 30 degrees: 25 points

at 5 sec	25	
else	0	

IV. <u>FLY APPROACH</u>		250 POINTS
Scored from GLS intercept to middle marker (1.0 nmi DME)		
GLS deviation held over 80% of the time:		75 points
+/- 1/4 dot	75	
+/- 3/4 dot	60	
+/- 3/4 dot	25	
else	0	
Localizer deviation held over 80% of the time:		75 points
+/- 1/2 dot	75	
+/- 3/4 dot	60	
+/- 1 dot	25	
else	0	
FPM on flight director over 80% of the time:		50 points
+/- 1/2 degree	50	
+/- 1 degree	30	
+/- 2 degrees	15	
+/- 3 degrees	10	
else	0	
AOA held 80% of the time:		50 points
+/- 10 - 13 degrees	50	
+/- 8 - 10 degrees	30	
+/- 5 - 8 or 13 - 14.5 degrees	10	
else	0	
V. <u>LANDING AND ROLLOUT</u>:		540 POINTS
<u>Decision Height Snapshot</u>: Scored when aircraft reaches 200 ft AGL		100 points
Localizer deviation:		25 points
+/- 1/4 dot	25	
+/- 1/2 dot	15	
+/- 3/4 dot	5	
else	0	

GLS deviation:		30 points
+/- 1/4 dot	30	
+/- 1/2 dot	15	
+/- 3/4 dot	5	
else	0	
Flight Path Angle from - 3.0 degrees:		25 points
+/- 1 degree	25	
+/- 1 3/4 degrees	15	
+/- 2 1/2 degrees	10	
else	0	
AOA:		25 points
10 to 13 degrees	25	
8 to 10 degrees	15	
5 to 8 or 13 to 14.5 degrees	5	
else	0	

<u>Decision Height to Flare</u>: 50 points

Scored from middle marker (1.0 nmi DME) to 25 ft AGL

All parameters scored based on 80% of the time

Localizer deviation:		30 points
+/- 1/4 dot	30	
+/- 1/2 dot	20	
+/- 3/4 dot	5	
else	0	
Flight Path Angle from -2.5 degrees		20 points
+/- 1 degree	20	
+/- 1 3/4 degrees	10	
+/- 2 1/2 degrees	5	
else	0	
AOA:		30 points
10 to 13 degrees	30	
8 to 10 degrees	20	
5 to 8 or 13 to 14.5 degrees	5	
else	0	

Flare (25 ft AGL) to Touchdown: 130 points

All items scored based on 80% of the time

Localizer deviation:		40 points
+/- 1/4 dot	40	
+/- 1/2 dot	25	
+/- 3/4 dot	10	
else	0	
Flight Path Angle:		40 points
0.0 to -2.0 degrees	40	
-2.0 to -2.5 degrees	25	
-2.5 to -3.5 degrees	10	
else	0	
AOA:		50 points
10 to 13 degrees	50	
8 to 10 degrees	30	
5 to 8 or 13 to 14.5	10	
else	0	

Touchdown Snapshot: 190 points
Scored one frame before touchdown

Centerline deviation:		50 points
+/- 35 ft	50	
+/- 50 ft	30	
+/- 75 ft	10	
else	0	
AOA:		45 points
10 to 13 degrees	45	
8 to 10 degrees	30	
5 to 8 or 13 to 14.5 degrees	15	
else	0	

Touchdown distance: Scored from where glidepath intercepts the runway		35 points
0 to 500 ft	25	
500 to 2,500 ft	35	
2,500 to 3,500 ft	15	
else	0	
Flight Path Angle:		25 points
0.0 to -1.5 degrees	25	
-1.5 to -2.5 degrees	15	
-2.5 to -3.5 degrees	5	
else	0	
Drift Velocity:		35 points
+/- 10 ft/sec	35	
+/- 30 ft/sec	15	
else	0	
Landing Roll:		35 points
Centerline deviation held: Scored based on 80% of the time		35 points
+/- 38 ft	35	
+/- 50 ft	25	
+/- 75 ft	10	
else	0	

VI. MISSED APPROACH

Tested between outer marker (5.0 nmi DME) and decision height (200 ft AGL)

If localizer deviation goes outside 1 dot, it should be a missed approach. A count of the number of times this deviation occurs is displayed.

If GLS deviation goes above or below 1 dot, it should be a missed approach. A count of the number of times this deviation occurs is displayed.

If RPMs gets greater than 85%, speed brakes go in, FPA gets greater than 2.5 degrees, and the gear goes up, then a missed approach is being executed and the run should be terminated. +200 points if missed approach performed and it was detected that a missed approach should occur. The check for a missed approach occurs from outer marker (5.0 nmi DME to 3 nmi past the GLS/runway intersection point.).

APPENDIX F

ILS EXPERIMENT PILOT BRIEFING

Objective

The primary objective of this research is to determine the most effective method of accomplishing instrument landings in poor weather conditions.

Simulation Equipment

In this research, you will perform a series of ILS approaches and landings in an F-16A flight simulator, which is equipped with fully operational flight controls and cockpit instrumentation. There is an operational HUD, and the in-cockpit radar display has been modified to provide head-down flight director information. The visual system can simulate both day and night scenes; and at night, the runway environment includes strobe lights, VASI lights, and runway centerline lights.

Flight Schedule

You will be in the simulator three times today, between 1 h and 1 1/2 h each time. The specific events in each of the three simulator sessions are as follows:

Session 1:	5-min free flight
	3 practice ILS approaches
	5 test ILS approaches
Session 2:	5 test ILS approaches
Session 3:	5 test ILS approaches

Familiarization and Practice

The 5-min free flight and 3 practice ILS approaches will be in the Tucson area. The free-flight time may be used at your discretion to become familiar with the simulation. In the practice trials, you will be initialized on a dogleg to Tucson ILS RWY 11L. You must perform a full-stop landing or execute a missed approach, at which time you will be reinitialized on the dogleg. During the practice trials, the HUD with the flight director and head-down flight director will be available. The layout and operation of the head-down flight director are depicted in the attached illustrations.

Ground control will give you the weather and clear you for the approach prior to each practice trial. The weather conditions in the familiarization period and practice trials are as follows:

Familiarization:	Day, clear, unlimited visibility, calm winds.
Practice 1:	Day, clear, unlimited visibility, calm winds.
Practice 2:	Night, VFR, clear, 10-kt wind.
Practice 3:	Night, 3-nmi visibility, 5,000-ft MSL cloud deck, calm winds.

Test Trials

Your task in the test trials is to perform an ILS approach and a full-stop landing or, if necessary, execute a missed approach. For these tests, an airfield was created called Robby. The simulator will be initialized on a dogleg to Robby ILS RWY 26 prior to each trial. An approach plate of the Robby environment is attached.

In each session, you will fly five test approaches under each of the following conditions:

Test 1:
- (a) HUD with flight director
- (b) No head-down instrumentation

Test 2:
- (a) HUD with localizer and GLS deviation bars
- (b) No HUD flight director
- (c) No head-down instrument

Test 3:
- (a) ALTM, AI, VVI, AOA indicator, ADI, HSI
- (b) Head-down flight director
- (c) No HUD

Test 4:
- (a) ALTM, AI, VVI, AOA indicator, ADI, HSI
- (b) No HUD
- (c) No head-down flight director

Test 5: (a) HUD with flight director

(b) Head-down flight director

(c) ALTM, AI, VVI, AOA indicator, ADI, HSI

The order of test conditions will be randomized, but the same order will be used in each session.

Prior to each trial, ground control will give you the weather and clear you for the approach. The weather on all test trials is as follows:

Night

Ceiling: 6,000 ft MSL

Scud

Scattered clouds: 500 - 1,500 ft AGL

Visibility: 1 1/2 mi

Winds: 15 kts (direct cross 166 at 15)

No ground fog

Performance Feedback

Feedback about your performance will be provided following each practice trial. However, feedback will not be provided for the test trials. After the three test sessions, you will be given a summary printout of your performance on the test trials.

Performance Scoring and Debriefing Questionnaire

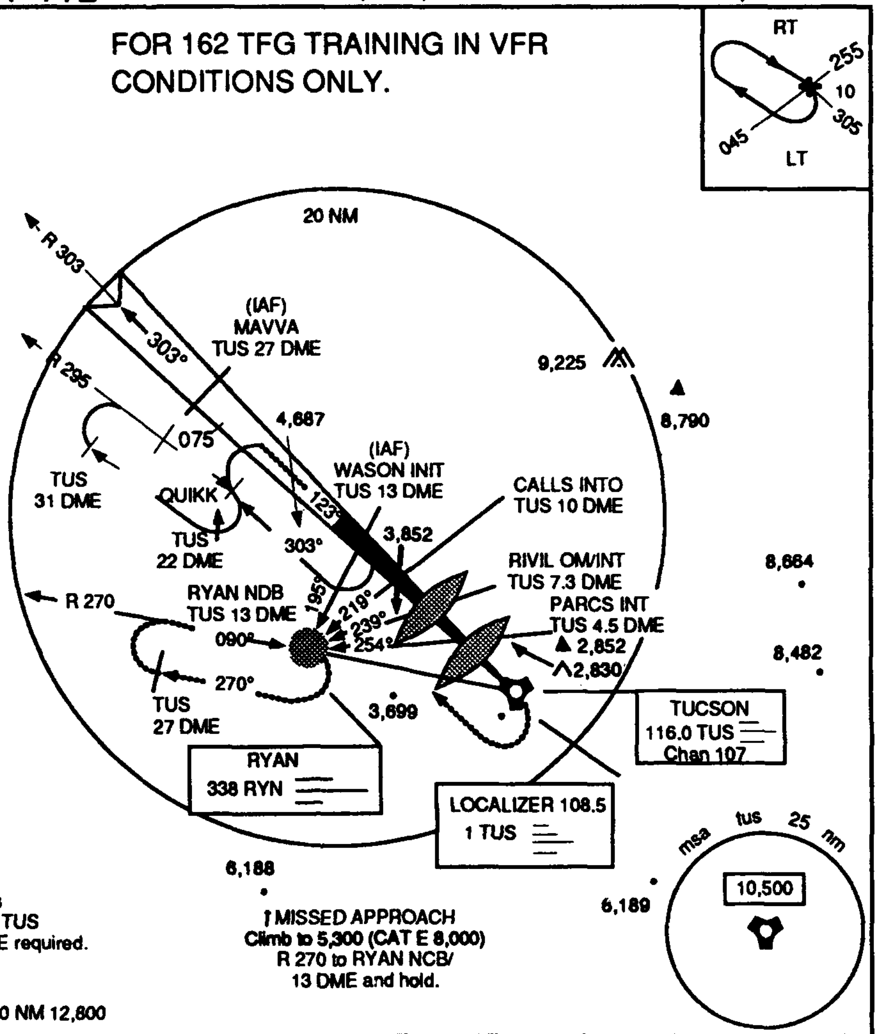
Your task performance will be automatically scored on the test trials. The test data will be used only in conjunction with this research, and you will not be identified by name. A debriefing questionnaire will be administered after the test sessions to solicit your opinion about the simulation and research.

Personal

Your participation in this research is vital. Please fly the best, most precise approaches you possibly can. From your data, we hope to eventually develop a simulator-based program of instruction and training for F-16 instrument landings.

TUCSON APP CON
1,240 360 d
TUCSON TOWER
118.3 257.8
GND CON
124.4 348.6
CLNC DEL
126.65 326.2
ATIS
123.8 320.1

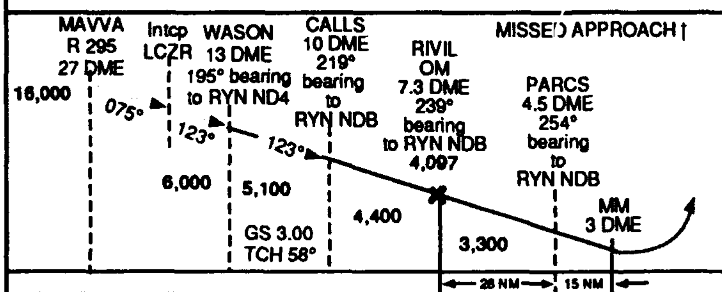
FOR 162 TFG TRAINING IN VFR CONDITIONS ONLY.

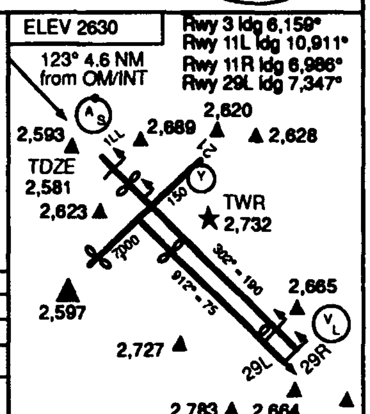


NOTE: Simultaneous reception of I TUS and TUS DME required.

↑MISSED APPROACH
Climb to 5,300 (CAT E 8,000)
R 270 to RYAN NDB/
13 DME and hold.

EMERG SAFE ALT 100 NM 12,800





CATEGORY	C	D	E
S ILS 11L	2,781 1/2	200	(200 1/2)
S LOC 11LL**	2,860 1/2 (300 1/2)	2,860 1/4 279	(300 1/4)
CIRCLING	3,160 1 1/2 530 (600 1 1/2)	3,180 2 550 (600 2)	3,680 3 1,050 (1,100 3)
S TAC 11L	2,940 1/2 359 (400 1/2)	2,940 1 359	(400 1)

** ADF OR DME REQUIRED FOR ILS/LOC *DISPLACED THRESHOLD

HIRL Rwy 11L 29R
MIRL Rwy 3 21
RE IL Rwy 11

32° 07'N 110° 56'W

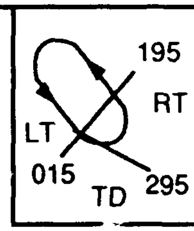
TOS APP CON
318.1 118.5

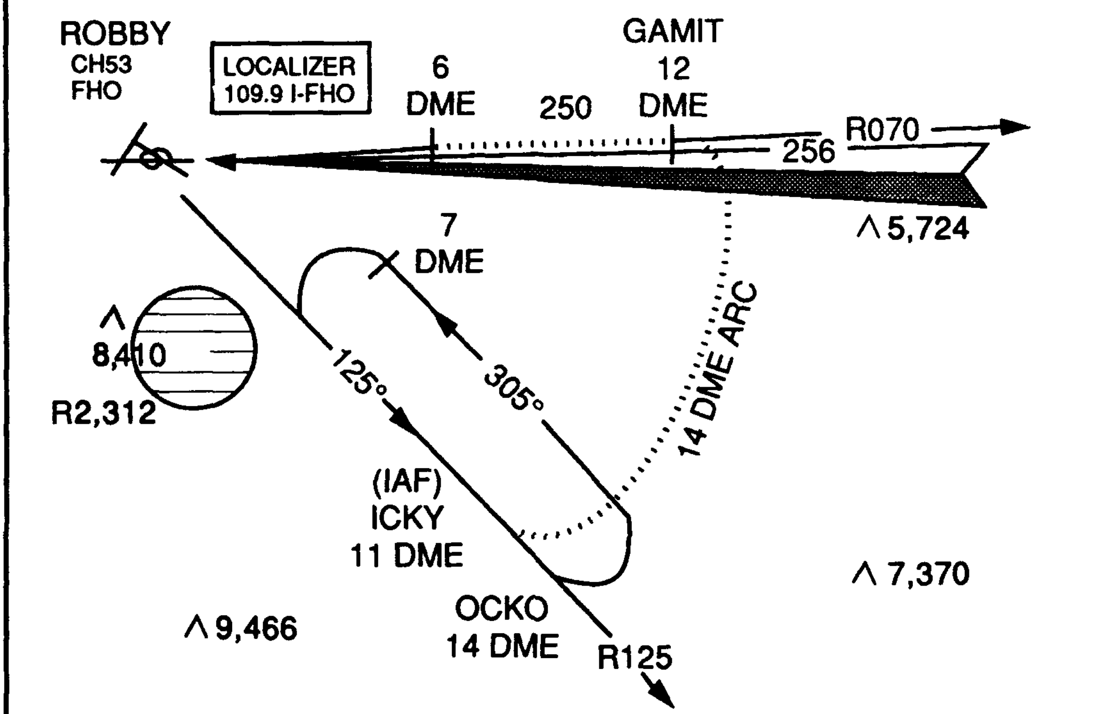
ROBBY TWR
229.6 118.9 41.50
GND CONTROL
248.2 121.7

ROBBY APP CON
234.4 237.5 119.5

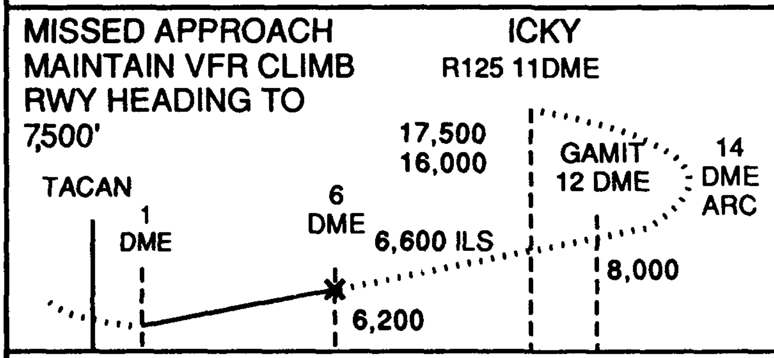
DAY VFR TRAINING ONLY

CAUTION - Unmarked and Lighted Balloon and Cable to 14,999 in R2,312

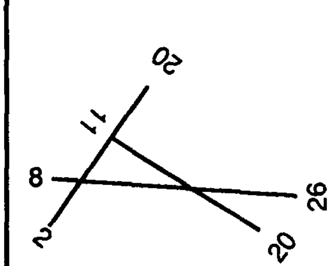




MISSED APPROACH
MAINTAIN VFR CLIMB
RWY HEADING TO
7,500'



ELEV 4,707



CATEGORY	A-E		
S-26/LOC	5,220-3	513	(1,500-3)
S-PAR	4,917-3	200	(1,500-3) G.S. 3.0°
S-ILS	4,917-3	200	(1,500-3)

APPENDIX G

DEBRIEFING QUESTIONNAIRE

Date ____________________ Last Four of SSN:____________

F-16 ILS EVALUATION

Directions: For those questions which ask you to indicate the extent to which you agree or disagree with a statement, circle the one response alternative that best describes your answer. The response format for all other items is self-explanatory. Your responses will be treated as confidential, reflecting your own personal opinion and not that of the Tactical Air Command or the United States Air Force.

1. I like the way this simulator flies.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

2. This F-16 simulator flies like the aircraft.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

3. The visual scene caused me disorientation.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

   a. The disorientation was predominately during the head-up phase.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

   b. The disorientation was predominately during the head-down phase.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

4. Participation in this research has changed my basic ILS technique.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

5. I fly better ILS approaches as a result of participating in this study.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

6. I like the head-down flight director.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

7. I would like to see head-down flight director moding in the aircraft.

Strongly Disagree	Somewhat Disagree	Undecided	Somewhat Agree	Strongly Agree

8. Were there any aspects of the simulation that you particularly liked? If so, please describe briefly.

9. Were there any aspects of the simulation that you particularly disliked? If so, please describe briefly.

10. What were your impressions of the visual simulation of the weather effects?

11. Were the lights on the runway disorienting? If so, when did they no longer seem confusing to you? (which trial number)

12. What do you think the toughest weather conditions for flying an ILS are?

13. If you could create confusing or difficult visual conditions that can reasonably be expected, what would they be?

APPENDIX H

DATA ANALYSIS TABLES

DECISION HEIGHT SNAPSHOT
Performance Data

Effect	Df	Flight Path Angle (in deg.) MS	F	p	Localizer Deviation (in 1/100 deg.) MS	F	p
CONDITION	4	1.23	3.54	0.0108	0.068	3.34	0.0144
ERROR	72	0.35	-	-	0.020	-	-

Condition Levels	Flight Path Angle Mean	SE	Localizer Deviation Mean	SE
HUD w/ FD	3.38	.132	-5	3.2
HUD w/o FD	3.51	.132	-6	3.2
Instr. only	3.92	.132	8	3.2
Head-down FD	3.48	.132	-4	3.2
HUD with all	3.27	.132	-3	3.2

Effect	Df	GLS Deviation (in 1/100 deg.) MS	F	p
CONDITION	4	0.366	3.71	0.0084
ERROR	72	0.099	-	-

Condition Levels	GLS Deviation Mean	SE
HUD w/ FD	5	7
HUD w/o FD	-1	7
Instr. only	28	7
Head-down FD	21	7
HUD w/ all	-1	7

TOUCHDOWN SNAPSHOT (CONTINUED)
Performance Data

		Distance to Touchdown (in ft)		
Effect	Df	MS	F	p
CONDITION	4	20,306.5	0.14	0.9656
ERROR	72	142,233.7	-	-

Condition Levels	Mean	SE
HUD w/ FD	1,182.24	84.3
HUD w/o FD	1,239.49	84.3
Instr. only	1,189.05	84.3
Head-down FD	1,168.94	84.3
HUD with all	1,156.13	84.3

FLY THE APPROACH
Performance Data

Effect	Df	Mean Flight Path Angle (in deg.) MS	F	p	SD Localizer Deviation (in 1/100 deg.) MS	F	p
CONDITION	4	0.001	0.61	0.6564	0.80	23.85	0.0001
ERROR	72	0.001	-	-	0.03	-	-

Condition Levels	Mean	SE	Mean	SE
HUD w/ FD	3.01	.007	.51	.041
HUD w/o FD	3.01	.007	.72	.041
Instr. only	3.00	.007	.99	.041
Head-down FD	3.01	.007	.80	.041
HUD with all	3.01	.007	.52	.041

Effect	Df	Mean Localizer Deviation (in 1/100 deg.) MS	F	p	SD Localizer Deviation (in 1/100 deg.) MS	F	p
CONDITION	4	0.04	7.29	0.0001	0.10	16.86	0.0001
ERROR	72	0.01	-	-	0.01	-	-

Condition Levels	Mean	SE	Mean	SE
HUD w/ FD	-6	1.6	11	1.7
HUD w/o FD	-2	1.6	24	1.7
Instr. only	5	1.6	25	1.7
Head-down FD	-0	1.6	19	1.7
HUD w/ all	-6	1.6	10	1.7

FLY THE APPROACH (CONTINUED)
Performance Data

		Mean GLS Deviation (in 1/100 deg.)			SD GLS Deviation (in 1/100 deg.)		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	0.01	4.97	0.0013	0.03	10.46	0.0001
ERROR	72	0.00	-	-	0.00	-	-

Condition Levels	Mean	SE	Mean	SE
HUD w/ FD	3	0.9	7	1.3
HUD w/o FD	1	0.9	10	1.3
Instr. only	7	0.9	16	1.3
Head-down FD	4	0.9	12	1.3
HUD w/ all	3	0.9	6	1.3

THE APPROACH
Scoring Algorithm

		GLS 4			Localizer 4		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	4,311.73	19.16	0.0001	99.96	3.70	0.0086
ERROR	72	225.09	-	-	27.03	-	-

Condition Levels	GLS 4 Mean	GLS 4 SE	Localizer 4 Mean	Localizer 4 SE
HUD w/ FD	57.833	3.355	75.000	1.163
HUD w/o FD	38.542	3.355	69.417	1.163
Instr. only	25.000	3.355	72.500	1.163
Head-down FD	33.750	3.355	74.250	1.163
HUD with all	57.625	3.355	74.167	1.163

		Flight Path Angle 4			AOA		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	10,827.40	244.02	0.0001	80.28	3.49	0.0115
ERROR	72	44.37	-	-	22.98	-	-

Condition Levels	Flight Path Angle 4 Mean	Flight Path Angle 4 SE	AOA Mean	AOA SE
HUD w/ FD	46.083	1.489	16.000	1.072
HUD w/o FD	0.667	1.489	10.667	1.072
Instr. only	0.167	1.489	13.000	1.072
Head-down FD	33.667	1.489	11.833	1.072
HUD w/ all	45.917	1.489	13.500	1.072

THE APPROACH
Scoring Algorithm

		Localizer 5			GLS 5		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	111.29	10.80	0.0001	209.26	3.95	0.0059
ERROR	72	10.30	-	-	52.92	-	-

Condition Levels	Localizer 5 Mean	Localizer 5 SE	GLS 5 Mean	GLS 5 SE
HUD w/ FD	24.667	0.718	15.167	1.627
HUD w/o FD	21.000	0.718	10.292	1.627
Instr. only	19.250	0.718	7.083	1.627
Head-down FD	22.750	0.718	8.583	1.627
HUD with all	24.667	0.718	12.750	1.627

		AOA 5			Flight Path Angle 5		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	83.78	4.46	0.0028	100.25	6.55	0.0001
ERROR	72	18.80	-	-	15.31	-	-

Condition Levels	AOA 5 Mean	AOA 5 SE	Flight Path Angle 5 Mean	Flight Path Angle 5 SE
HUD w/ FD	14.583	0.969	22.450	0.875
HUD w/o FD	11.000	0.969	20.708	0.875
Instr. only	11.000	0.969	17.041	0.875
Head-down FD	9.292	0.969	19.542	0.875
HUD w/ all	13.000	0.969	22.333	0.875

TOUCHDOWN SNAPSHOT
Scoring Algorithm

		Centerline 8			AOA 8		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	34.00	2.69	0.0378	134.44	2.01	0.1028
ERROR	72	12.64	-	-	67.03	-	-

Condition Levels	Mean	SE	Mean	SE
HUD w/ FD	50.000	0.795	31.250	1.831
HUD w/o FD	47.000	0.795	26.500	1.831
Instr. only	49.333	0.795	27.125	1.831
Head-down FD	47.333	0.795	28.750	1.831
HUD with all	49.000	0.795	32.500	1.831

		Distance 8			AOA		
Effect	Df	MS	F	p	MS	F	p
CONDITION	4	14.003	0.51	0.7286	7.31	0.50	0.7324
ERROR	72	27.46	-	-	14.503	-	-

Condition Levels	Mean	SE	Mean	SE
HUD w/ FD	26.333	1.172	20.917	0.852
HUD w/o FD	27.750	1.172	21.167	0.852
Instr. only	28.667	1.172	20.000	0.852
Head-down FD	27.708	1.172	19.833	0.852
HUD w/ all	27.792	1.172	20.917	0.852

TOUCHDOWN SNAPSHOT (CONTINUED)
Scoring Algorithm

		Drift 8		
Effect	Df	MS	F	p
CONDITION	4	3.78	2.25	0.072
ERROR	72	120.88	-	-

Condition Levels	Mean	SE
HUD w/ FD	35.000	0.290
HUD w/o FD	35.000	0.290
Instr. only	34.667	0.290
Head-down FD	34.000	0.290
HUD with all	35.000	0.290

APPENDIX I

ACRONYMS

ADI	Altitude Direction Indicator
AF	Air Force
AFM	Air Force Manual
AFR	Air Force Reserve
AGL	Above Ground Level
AI	Airspeed Indicator
ALTM	Altimeter
ANG	Air National Guard
ANOVA	Analysis of Variance
AOA	Angle-of-Attack
AOI	Area of Interest
AVTS	Advanced Visual Technology System
CIG	Computer Image Generator
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
FPM	Flight Path Marker
GEGS	General Electric Government Services
GLS	Glideslope
HDD	Head-Down Display
HSI	Horizontal Situation Indicator

HUD	Head-Up Display
ILS	Instrument Landing System
IOS	Instructor Operator Station
MANOVA	Multivariate Analysis of Variance
MSL	Mean Sea Level
NAV	Navigation
REO	Radar Electro-Optical
RPM	Revolutions per Minute
SAS	Statistical Analysis System
SD	Standard Deviation
SDO	Spatial Disorientation
TACAN	Tactical Air Navigation
TFG	Tactical Fighter Group
UDRI	University of Dayton Research Institute
USAF	United States Air Force
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Restrictions
VVI	Vertical Velocity Indicator

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